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DEMONSTRATION/VALIDATION OF THE SNAP SAMPLER PASSIVE GROUNDWATER SAMPLING DEVICE AT THE FORMER McCLELLAN AIR FORCE BASE

Louise Parker, Nathan Mulherin, Tommie Hall, Constance Scott, Kelsey Gagnon, Jay Clausen, William Major, Richard Willey, Jacob Gibs, Thomas Imbrigiotta, and Donald Gronstal

February 2011

FINAL REPORT (Version 2)

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS USED IN THE TEXT

Å	Angstrom
AFB	Air Force Base
Al	Aluminum
AMSL	Above Mean Sea Level
As	Arsenic
ASTM	American Society for Testing and Materials (now known as ASTM International)
Ba	Barium
BGS	Below Ground Surface
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
Ca	Calcium
Cd	Cadmium
cDCE	*cis*,1,2-DCE
CERCLA	Comprehensive Environment Response and Liability Act (i.e., Superfund)
Co	Cobalt
Cr	Chromium
CRREL	Cold Regions Research and Engineering Laboratory
Cu	Copper
DI	Deionized water
DO	Dissolved Oxygen
DoD	U.S. Department of Defense
ERDC	U.S. Army Engineer Research and Development Center
Fe	Iron
gpd	Gallons per Day
HDPE	High Density Polyethylene
Hg	Mercury
ICP	Inductively Coupled Plasma
ICP/MS	Inductively Coupled Plasma Mass Spectrometry
IROD	Interim Record of Decision
ITRC	Interstate Technology and Regulatory Council
K	Potassium
Kow	Octanol/Water Partition
$k	thousand dollars
LDPE	Low-Density Polyethylene
LTM	Long Term Monitoring
MCL	Maximum Contaminant Level
Mg	Magnesium
Mn	Manganese
Mo	Molybenum
MS	Matrix Spike sample
MSD	Matrix Spike Duplicate sample
MTBE	Methyl Tert-Butyl Ether

mXYL	*m*-Xylene
Na	Sodium
NELAC	National Environmental Laboratory Accreditation Conference
Ni	Nickel
NJDEP	New Jersey Department of Environmental Protection
NTU	Nephelometric Turbidity Units
ORP	Redox potential
OU	Operable Unit
Pb	Lead
PCBs	Polychlorinated biphenyls
PCE	Tetrachloroethylene
PDB	Polyethylene Diffusion Bag sampler
PE	Polyethylene
POC	Points of Contact
PP	Polypropylene
ppb	Parts per billion
QA	Quality Assurance
QC	Quality Control
RGC	Regenerated Cellulose
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Studies
RM-ANOVA	Repeated Measures Analysis of Variance test
ROD	Record of Decision
RPD	Relative Percent Difference
RPP	Rigid Porous Polyethylene sampler
RSD	Percent Relative Standard Deviation
S	Sulfur
Sb	Antimony
SI	Site Investigation
SO4	Sulfate
SS	Stainless steel
SVE	Soil Vapor Extraction
TCE	Trichloroethylene
TDS	Total Dissolved Solids
USEPA	U.S. Environmental Protection Agency
V	Vanadium
VOA	Volatile Organic Analyte
VOC	Volatile Organic Compound
Zn	Zinc

EXECUTIVE SUMMARY

This report was completed as a partial fulfillment of the obligations established for ESTCP Demonstration project ER-0630. The objectives of this project were to demonstrate that the Snap Sampler passive groundwater sampling device can provide 1) technically defensible analytical data for the wide spectrum of analytes that are of concern to the Department of Defense (DoD), and 2) substantial cost savings. Our research plan was to use this device to collect samples at several sites for a range of analyte types, including VOCs, explosives, perchlorate, metals, and natural attenuation parameters. This particular demonstration was conducted at the former McClellan Air Force Base in Sacramento, CA, and is the first time we have used the Snap Sampler to collect samples for several types of analytes: dissolved and total inorganics (including non-metal anions, metalloids, and metals), and four VOCs (three chlorinated solvents and methyl tert-butyl ether [MTBE]).

For this demonstration, 10 wells were sampled. Nine of the 10 wells were constructed with PVC casings and stainless steel screens, and the other well was constructed with low-carbon steel casing and screen. Each well was sampled using Snap Samplers, Regenerated Cellulose (RGC) passive diffusion samplers, and the USEPA Region 1's (1996) low-flow purging and sampling protocol. Several performance criteria were used to determine whether these passive sampling methods provided technically defensible data: 1) that the method could be used to collect samples for a range of contaminants at the site, 2) that the method provided reproducible results (i.e., among field duplicate samples), and 3) that there was agreement between the passive sampling methods and low-flow purging and sampling for the analytes of interest.

The Snap Sampler was able to collect adequate sample volume of for all of the analyses, including requirements for additional QA/QC samples. This sampling method provided reproducible data for the VOCs, dissolved inorganics, and total non-metal ions. However, this was not the case for several of the total metals, where *both* the Snap Sampler *and low-flow samples* had high variability among the field duplicate samples for Cr, Fe, and Mn. This was also true for *both* sampling methods for Co, Cu, and Mo; however, concentrations of these analytes were at or near the reporting limit. The Snap Sampler variability was also greater than our guideline for V samples.

Generally, there was excellent agreement between analyte concentrations in the Snap Sampler and low-flow sampling and these relationships were linear with the slopes equal to 1.0. There were no statistically significant differences between analyte concentrations in the Snap Sampler and the low-flow sampling for the VOCs, dissolved inorganics, total non-metal anions, and most of the total metals and metalloids. The exceptions to this were for total Fe and total Mn, where concentrations were significantly higher in the Snap Sampler samples.

We believe that there may have been several causes for the elevated concentrations of total Fe and Mn in the wells and, thus, Snap Sampler samples, and that the causes may have varied some from well to well. These causes include: 1) leaching of metal constitu-

ents of the stainless steel screens and low-carbon steel casing and screen; 2) corrosion of the well screens, allowing fines to enter the well; and 3) an experimental artifact caused when all the sampling equipment was placed in the well. When the equipment was added to the well, this caused agitation that elevated the level of fines in the well and also caused the formation of hydrous iron, and possibly manganese, oxides

The Snap Sampler was found to be relatively easy to use in that 1) the technician was able to learn how to use the sampler with relative ease, 2) there were relatively few problems that required a second sampling attempt, and 3) the method was acceptable to the field technician.

The Snap Sampler also provided lower costs than low-flow sampling. Sampling time was less than one fourth of that needed to collect low-flow samples at the site. The long-term costs associated with using these methods were calculated based on the costs of this demonstration. The projected long-term costs were determined for a similar site with 50 wells where quarterly sampling is conducted over 10 years. Based upon these calculations, the Snap Sampler can provide a 46% cost savings vs. using low-flow sampling. These cost savings are based upon collecting samples for VOCs, total metals and metalloids, total anions, dissolved metals and metalloids, and for dissolved and total Fe(2) for field analyses. In contrast, we determined that the cost savings associated with using the Snap Sampler at the former Pease AFB, where samples were collected only for inorganic analytes, was 67% (Parker et al. 2009).

The RGC sampler provided adequate sample volume for the analyses of VOCs and dissolved inorganic analytes. However, because of the small pore size of the RGC membrane, this sampler could not be used to collect samples for total inorganic analytes. This may prevent its use for risk assessment as most risk assessors are interested in the total contaminant load. For the remaining analytes that this sampler can be used for, there was generally good agreement between the field replicate samples.

For the VOCs, the RGC sampler recovered equivalent concentrations of carbon tetrachloride and cDCE. In contrast, concentrations of MTBE and acetone were detected in the RGC samples but not in the low-flow or Snap Sampler samples, or the RGC equipment blanks. We were not able to determine why this was the case for MTBE but suspect that acetone was a contaminant in the bottled distilled water that was purchased on site (and used only for these samplers). In contrast, concentrations of TCE were significantly lower in the RGC samplers than in the low-flow samples. For the dissolved metals and metalloids, there was good agreement between the two sampling methods (low-flow and the RGC sampler) for As, Ca, Cr, Ni, and V. Concentrations were significantly higher for Ba, Mg, K, and Na in the RGC sampler; however, these differences were very small, especially for Ba, Mg, and Na.

Because the RGC sampler can undergo biodegradation, using it requires two trips to the field: one to deploy the sampler and the other to retrieve the samples. As a result, the labor savings with this sampler are slightly less than with the Snap Sampler. However, the time needed for sampling with this device is less than one third of that needed for low-

flow sampling. Cost savings for this sampler at this site were 67%, which is nearly equivalent to those we found at the former Pease AFB (71%) where only inorganic analytes were sampled.

We believe that this demonstration has shown that the Snap Sampler can be used to successfully sample a site for a number of different analyte types, including VOCs, dissolved inorganic analytes, and most (if not all) total inorganic analytes. The Snap Sampler recovered concentrations of metals that were comparable to those obtained using low-flow purging and sampling, took considerably less time to collect samples than low-flow sampling, and was considerably less expensive than low-flow sampling. We also found that the RGC sampler is an economic alternative for collecting samples for VOCs and dissolved inorganic analytes.

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1.0 INTRODUCTION

1.1 BACKGROUND

Because of their ease of use and cost-savings, passive sampling techniques continue to garner interest from the user and regulatory communities. Passive sampling techniques rely on the continuous natural flow through the well screen (Robin and Gillham 1987; Powell and Puls 1993). Most research to date (Gillham et al. 1983; Robin and Gillham 1987; Powell and Puls 1993) indicates that water in the screened portion of the well is representative of the geological formation if the well has been designed and developed properly. Therefore, where the use of passive sampling is appropriate, cost reductions can include better delineation of contamination with depth within the screened zone (in stratified wells), reduced volumes of purge water waste, reduced labor during sampling, and reduced equipment costs.

In an effort to promote acceptance of passive sampling methods, the Interstate Technology & Regulatory Council [ITRC] Diffusion/Passive Samplers Team has written several documents on various passive sampling approaches (2004, 2006, 2007) and there have been numerous research studies that have compared the comparability of passives sampling methods with older, more accepted methods such as low-flow purging and sampling. According to the ITRC diffusion/passive samplers team (ITRC 2006), there are three classes of passive samplers: diffusion samplers, accumulation samplers, and equilibrated-grab samplers.

This study focuses on the Snap Sampler, which is an equilibrated-grab sampler. Equilibrated-grab samplers are left in the well for an equilibration period before collecting a sample. This equilibration period allows time for the well to recover from any disturbance caused by placing the device in the well, allows time for the natural flow pattern in the well to be reestablished, and for the materials in the sampler to equilibrate with the analytes in the well water, thereby preventing losses of analytes from sorption by the sampler materials. By allowing time for the well to recover prior to collecting the sample, the well is less agitated during the sampling event and particles that are not normally mobile in the formation are less likely to be entrained in the sample when it is collected. The time needed for equilibration will depend upon the sampling device and the materials in the sampler, the physical and chemical properties of the analytes, the ambient flushing rate of the well, and water temperature. The ITRC recommended a minimum deployment time of 2 weeks for most passive samplers (ITRC 2004, 2007). However, many of these samplers can be left in the well for quarterly, semiannual, or annual sampling events, thereby eliminating a second trip to the field.

Reported advantages associated with using a Snap Sampler vs. other passive samplers include that 1) the sample can be collected at a discrete depth within the well; 2) the sample is collected in sample bottles that are sealed under *in situ* conditions, thereby eliminating concerns about contamination as the sampler is removed from the well; 3) the sample is collected at a discrete point in time (vs. accumulation and diffusion samplers that collect a sample over a longer period); and 4) the sample does not have to be trans-

ferred to another container at the surface. The last feature reduces, or eliminates, losses of volatiles, dissolved gases, or metals that are subject to oxidation/precipitation reactions that can occur at the wellhead during bottle filling. Also, data quality improvements can result in wells with vertical stratification when passive sampling methods are used to delineate contaminant stratification.

Estimated cost savings associated with using the Snap Sampler (vs. low-flow purging and sampling) have ranged from 28% at the former McClellan AFB in CA (Parsons Inc. 2005) to 67% at the former Pease AFB in NH (Parker et al. 2009).

1.2 OBJECTIVES OF THE DEMONSTRATION

The objectives of this demonstration/validation project were to show that the Snap Sampler passive groundwater sampling device can provide 1) technically defensible analytical data for the wide spectrum of analytes that are of concern to the Department of Defense (DoD), and 2) substantial cost savings. A third objective was to facilitate technology transfer and acceptance of this sampling method. The Snap Sampler is an equilibrated grab sampler (ITRC 2006, 2007) that allows one to collect a whole water sample under *in situ* conditions without agitating the well during collection. Once the samples are collected, they can remain in the sampling bottle and do not require transfer to another container after they are recovered from the well, thereby reducing the possibility of loss of volatiles, reaction of analytes with the air during transfer, or contamination by the air.

The research plan was to collect samples at two sites with 1) the Snap Sampler, 2) low-flow purging and sampling (EPA Region 1, 1996), and 3) (where applicable) passive diffusion samplers such as the Regenerated Cellulose (RGC or dialysis membrane) sampler. Analytes to be included in this demonstration included VOCs and inorganic analytes with some natural attenuation parameters. Using these three sampling technologies allows one to compare dissolved and colloid-borne contaminants (such as metals). The first field demonstration for this project (Parker et al. 2009) was conducted at the former Pease AFB (Portsmouth, NH) and a range of inorganic analytes, including non-metals, transition metals, alkaline earth metals, alkali metals, and a metalloid, were sampled.

This particular demonstration took place at the McClellan Air Force Base (AFB) in Sacramento, CA. Found at this site were four VOCs and a suite of inorganic analytes, including two non-metal anions, a metalloid, two alkali metals, three alkaline earth metals, and nine transition metals. Concentrations in samples taken with the Snap Sampler were compared with those taken using low-flow sampling and the RGC passive diffusion sampler. For the inorganic analytes, both filtered and unfiltered samples were compared.

1.3 REGULATORY DRIVERS

Currently, the preferred method for sampling a groundwater monitoring well is to use a low-flow purging and sampling method first outlined by Puls and Barcelona (1996) and now promulgated by the USEPA Region 1 (1996), Nielsen and Nielsen (2002), and the ASTM (2003). However, because low-flow sampling draws water most heavily from the most permeable part of the geological formation, which may not be the area of interest, it does not allow vertical profiling of the contaminant plume, and is time consuming and expensive. So, finding a sampling method that is less labor-intensive and costly but able to yield quality data is clearly needed.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DESCRIPTION

While most previous research and development of passive groundwater samplers has focused on diffusion-based devices, the Snap Sampler (Fig. 2-1) is a grab-type device that was initially developed by Sanford Britt (ProHydro, Inc.) to improve data quality for VOCs. Specifically, the initial objectives were to 1) collect a sample at discrete levels in the well that would allow profiling contamination with depth, 2) reduce inconsistencies associated with the sampling methods and personnel, and 3) reduce losses during sample transfer. However, the applicability of this device to a broad spectrum of analytes was evident immediately because it presumably can collect a whole water sample under *in situ* conditions without agitating the well during collection, and can be used to sample any of the analytes of concern to the Department of Defense (DoD). Typically, after these samplers are deployed, the well is left and allowed time to re-equilibrate with the natural groundwater flowing through the well.

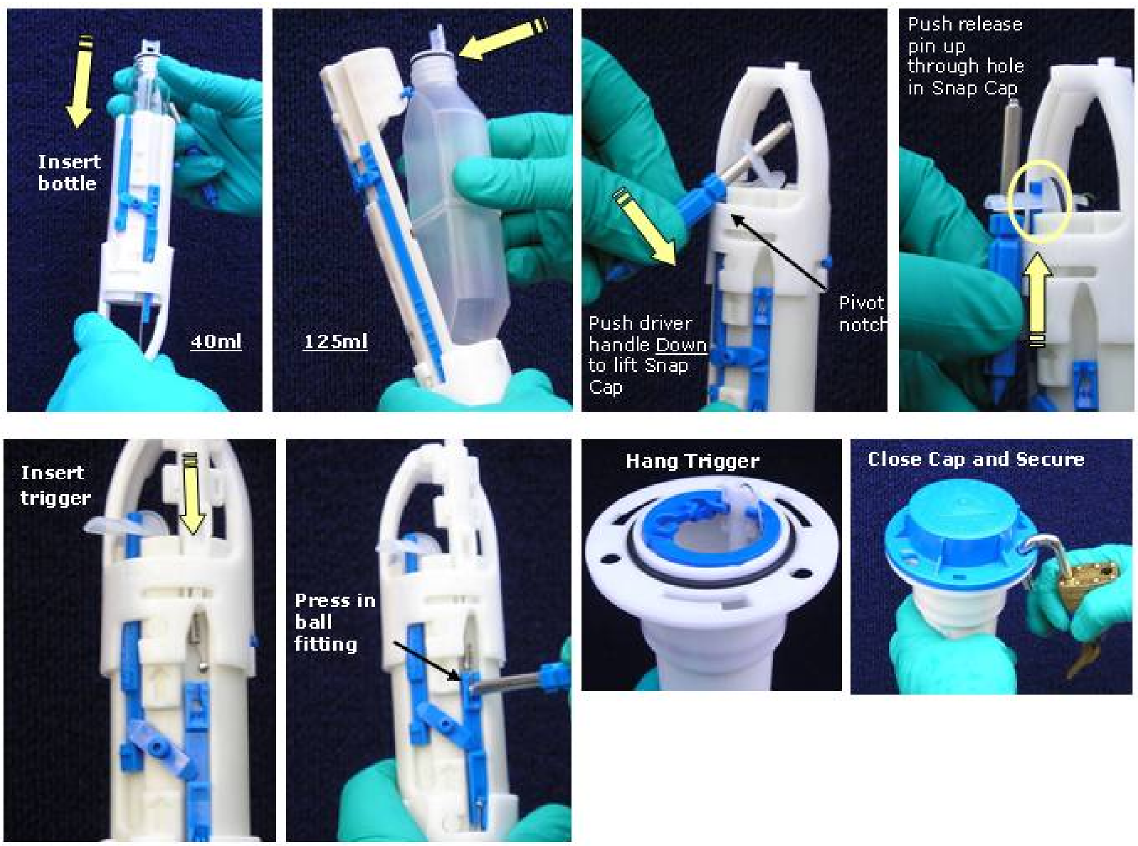


Figure 2-1. Snap Sampler deployment procedure.

The Snap Sampler consists of the sampler body that holds the sample bottle in place, a sample bottle that is open on both ends, and a trigger mechanism and trigger line. The device is deployed so that both ends of the sample bottle are open, and the trigger releas-

es spring-activated end caps that seal the bottle. The trigger line is attached to a well docking station during deployment; this ensures that the sampler remains at the desired depth in the well. Components of the plastic Snap Sampler and its deployment are shown in Figure 2-1. (If preferred, stainless steel sampler bodies can also be purchased.) This sampler is different from most in that the samples can remain in the bottle and do not require additional transfer to another container after they are recovered from the well. Currently, 40-mL glass VOA vials, 125-mL high-density polyethylene (HDPE), and 350-mL HDPE bottles are available. The 350-mL bottle fits in 4-in. diameter wells (and larger). The VOA vials and the 125-mL bottles fit in 2-in. diameter wells (or larger). The VOA vials can be used in common laboratory autosampler equipment. Multiple bottles can be deployed in tandem on a single trigger line or on multiple trigger lines when different types of samples need to be collected or when larger sample volumes are required. Up to six Snap Samplers can be deployed in tandem on a single trigger line, depending upon the type of trigger mechanism. The types of trigger mechanism included mechanical, electronic, and pneumatic. Electronic or pneumatic trigger devices are needed for deeper wells or for deploying larger numbers of samplers on a line.

2.2 TECHNOLOGY DEVELOPMENT

Parsons Inc. (2005) conducted a field study at the former McClellan Air Force Base evaluating six different passive samplers, including the Snap Sampler. In this study, analyte concentrations in samples taken with the various passive samplers were compared with analyte concentrations in samples that were taken using two pumped sampling methods, low-flow purging and sampling and a well-volume purging and sampling method (where the well was purged of three to five well volumes and then a sample was collected using a bailer). For the Snap Sampler, analytes that were compared included several VOCs (including 1,4-dioxane) and anions. This work has not been published in a peer-reviewed journal but the final report is available on line.

Interpreting the results is difficult because of differences in the sampling methods that were used (including sampling day) and in sample handling (some VOC samples were poured into a second container while others weren't), the numerous methods that were used to analyze the data, and issues with some of statistical analyses (e.g., the raw data were pooled for the various analytes prior to conducting the statistical analyses). However, regression plots of the pooled VOC data were informative. These plots showed that the Snap Sampler VOC concentrations correlated well with those taken using low-flow purging and sampling ($r^2 = 0.995$), although the Snap Sampler concentrations were higher (the slope was 1.77). In contrast, a similar comparison of the Snap Sampler and three-well volume samples indicated that the concentrations of VOCs agreed well ($r^2 = 0.90$ and a slope of 1.04). The findings were similar for the anions. That is, concentrations of the anions were higher in the Snap Sampler than they were in the low-flow samples (with a slope of 1.22) but were similar in magnitude in the Snap Sampler and the three-well volume purged samples (with a slope of 1.08). There could be several reasons why VOC concentrations would be lower in the low-flow samples. First, the Grundfos pump used for the low-flow samples could have caused losses of VOCs by heating of the well water. (In contrast, the three-well volume samples were not collected by pumping but were collected with a bailer.) However, this would not explain why the anion concentrations were

also lower in the low-flow samples. Another explanation for the lower concentrations of analytes is that new LDPE tubing was used to collect the low-flow samples. However, while we might expect some losses of VOCs to new LDPE tubing (Parker and Ranney 1998), anions are not readily sorbed by polyethylene (Masse et al. 1981; Parker et al. 1990). (Neither the Snap Sampler samples nor the pumped samples were composited in the lab.)

Our laboratory has conducted both laboratory and field studies that have evaluated the ability of the Snap Sampler to recover representative concentrations of VOCs and explosives in groundwater (Parker and Mulherin 2007). The laboratory studies were conducted at room temperature (~ 20 to 22°C) in a 244-cm (8-ft) tall, 20-cm (8-in.) diameter PVC standpipe that contained known concentrations of a suite of VOCs, explosives, or inorganic analytes (both cations and anions, including perchlorate). The data (on an analyte-by-analyte basis) were statistically analyzed to determine if the concentrations of analytes in samples taken with the Snap Sampler were significantly different from known concentrations of the analytes in samples collected from the standpipe (i.e., control samples). The Snap Sampler recovered comparable concentrations of all the analytes following a brief equilibration period. For VOCs, a 3-day equilibration period was adequate for most of the analytes to reach equilibrium with the materials in the sampler (Parker and Mulherin 2007). For explosives, 24 hours was sufficient for equilibration to occur (Parker and Mulherin 2007).

In our field studies (Parker and Mulherin 2007; Parker et al. 2008, 2009), we have evaluated the ability of this sampler to recover equivalent concentrations of various analytes when compared with the EPA's low-flow purging and sampling method (USEPA Region 1 1996). In Parker and Mulherin (2007) analytes included VOCs and explosives, and field sites included our own laboratory (CRREL in Hanover, NH), the Silresim Superfund site in Lowell, MA, and the former Louisiana Army Ammunition Plant in Minden, LA. At CRREL, one of our TCE contaminated wells was sampled on five different days using both sampling methods. At the Silresim site, four wells were sampled for 13 VOCs that included BTEX compounds and several chlorinated VOCs. At LAAP, five wells were sampled for seven explosive compounds and their daughter products.

The results of the statistical analyses of the data from the CRREL and Silresim sites indicated that there were no statistically significant differences between the VOC concentrations in the samples taken with the Snap Samplers vs. those in the samples taken using low-flow purging and sampling. A similar comparison of the data from the former LAAP also indicated that the Snap Sampler recovered comparable concentrations of explosives when compared with low-flow sampling.

Subsequent to this work, laboratory studies that evaluated the ability of the Snap Sampler to recover representative concentrations of inorganic analytes were conducted as part of earlier work for this demonstration project (Parker et al. 2008, 2009). These tests were conducted at room temperature in a standpipe (as described previously) that contained known concentrations of a suite of inorganic analytes (both cations and anions, including perchlorate). Analysis of the data revealed that the Snap Sampler recovered comparable

concentrations (i.e., > 99% recovery) of all the analytes following a brief (48-hour) equilibration period. Precision among the replicate samples was excellent, with the relative standard deviation generally less than 2% (and less than 10% in all cases).

Also, as part of this demonstration project, we conducted a field study at the former Pease AFB (Parker et al. 2008, 2009). This study evaluated the ability of the Snap Sampler and the RGC sampler to recover equivalent concentrations of inorganic analytes when compared with the EPA's low-flow purging and sampling (USEPA Region 1 1996). Inorganic analytes included non-metals (bromide, chloride, nitrate, perchlorate, and sulfate); a metalloid (As), and several metals, including alkali metals (sodium [Na] and potassium [K]); alkaline earth metals (magnesium [Mg], and calcium [Ca]); and transition metals (cadmium [Cd], chromium [Cr], manganese [Mn], and iron [Fe]). Statistical analyses of the data (on an-analyte-by-analyte basis) revealed that the Snap Sampler generally recovered samples with equivalent concentrations of inorganic analytes to those found using the EPA's low-flow purging and sampling protocol. This was true for both filtered and unfiltered samples, with the exception of the total Fe samples (Table 2-1). For each analyte, linear regression analyses of the Snap Sampler data vs. low-flow data generally showed a strong correlation, with the slope of the line not significantly different from 1.0 in most instances. A typical example for total Mg can be seen in Figure 2-2. In contrast, the results for total Fe are shown in Figure 2-3.

Table 2-1. Results from the statistical analyses of the data from the former Pease AFB.

Analyte	Significant Difference?	
	Dissolved species	Total species
As	No	No
Ca	No	No
Fe	No	Yes
Mg	No	No
Mn	No	No
K	No	No
Na	No	No

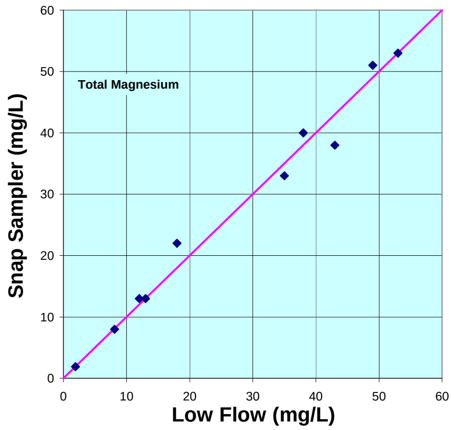


Figure 2-2. Linear plot of the Snap Sampler and low-flow data for total Mg (with the slope = 1.0).

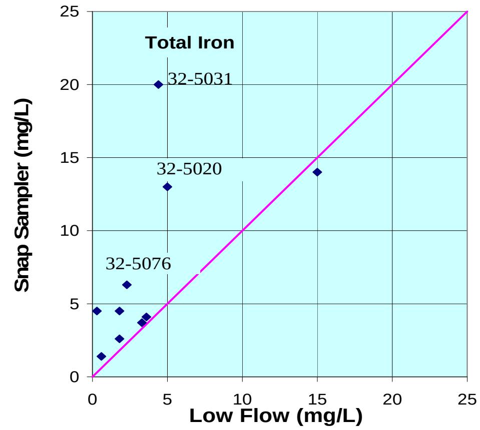


Figure 2-3 Linear plot of the Snap Sampler and low-flow data for total Fe (with the slope = 1.0).

We believe that the elevated Fe was the result of the elevated turbidity in some wells. In some cases, we believe that the elevated turbidity was the result of well-construction practices or possibly degradation of the stainless steel screen. However, for most of the wells, the elevated concentrations of unfiltered Fe appeared to be the direct result of disturbance of the well resulting from installing several pieces of sampling equipment simultaneously. This is an issue we wanted to examine in more depth in this study. The RGC sampler also provided samples with equivalent concentrations of these inorganic analytes when compared with unfiltered low-flow samples. The use of the RGC sampler in conjunction with low-flow sampling and the Snap Sampler demonstrated that colloidal transport of these analytes was not predominant at this site. This can also be seen by comparing the analyte concentrations of the filtered vs. unfiltered samples as shown in Figure 2-4 for Mg.

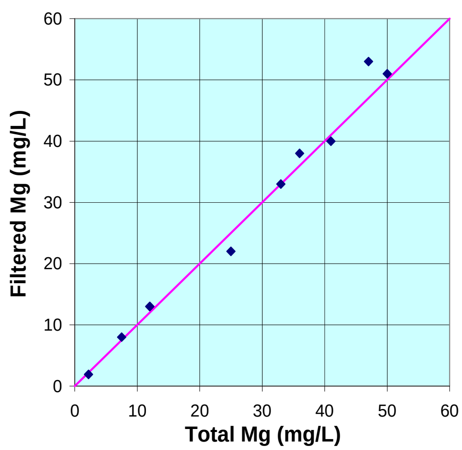


Figure 2-4. Plot showing the relationship between filtered and total concentrations of Mg.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Reported advantages associated with using the Snap Sampler include that it collects a whole water sample under *in situ* conditions, does not agitate the well during sample collection, can be used to collect a sample at a discrete depth in the well, and can be used to sample a broad spectrum of analyte types. In addition, samples do not require additional transfer to another container after collection, there is no purge water generated that requires disposal, and there are no power requirements for this sampler. Because samples can remain in the original bottle in which they were collected, presumably losses of volatiles and changes in concentrations of dissolved gases or analytes subject to oxidation/precipitation reactions (that can occur during transfer) are reduced or eliminated. Data uncertainty attributable to variability in sampling technique (associated with different personnel), hot or sunny weather, and exposure to the atmosphere (and any airborne contaminants) presumably are also reduced.

While the HydraSleeve is similar in many respects (i.e., it can be used to collect a whole water sample, it can be used to sample for any type of analyte), the samples are not necessarily collected at a discrete depth in the well but rather over an interval that is approximately 1.5 times the length of the sampler. Also, although the reed valve on the HydraSleeve closes once the sampler is full, the Snap Sampler bottle is sealed tightly at the sampling depth, and there is no need to transfer the sample at the wellhead with the Snap Sampler as with a HydraSleeve sampler.

Because the Snap Sampler is deployed before sampling to allow the well to recover from any disturbance from placing it in the well, and because this device collects a whole water sample instantaneously, presumably samples collected with this sampler should not have elevated turbidity (i.e., soil-derived, non-transportable particles). Thus, they should reflect the true naturally mobile colloid-borne contaminants flowing through the well. In contrast, even low-flow sampling has been shown to artificially elevate particle levels in some wells (Bailey et al. 2005), and most diffusion samplers cannot collect colloidal particles because of the small pore sizes of the membranes.

Previous studies by our laboratory (Parker and Ranney 1998) have demonstrated that when low-flow purging and sampling is used, sorption by longer lengths of polymer tubing can substantially reduce concentrations of some VOCs. In contrast, there are no losses of these analytes in samples collected with a Snap Sampler that has been equilibrated (Parker and Mulherin 2007). Also, the Snap Sampler can be used to collect a sample at a discrete depth in the well, whereas the low-flowing sampling collects a sample that is a flow-weighted average over the screened interval.

One final advantage of using the Snap Sampler is that it can be used to sample wells with slow recharge. This is also true for all passive (no-purge) samplers whether they are diffusion samplers such as the PDB sampler or another grab-type device such as the HydraSleeve. In contrast, any purging method that removes all the water from the well will yield suspect samples, especially for volatiles and analytes subject to oxidation/precipitation reactions.

The principal limitations with this technology are well diameter and sample volume. The conventional Snap Sampler bottles do not fit in wells smaller than 2 in. in diameter. The sample volume collected with these samplers may not be adequate for the chemical analyses, especially if there are a number of different analyte types that require separate volumes of sample for analyses. Using multiple samplers can increase sample volume (either on multiple trigger lines or in tandem on the same trigger line). According to the manufacturer, up to four samplers can be deployed in tandem on the same trigger line using a conventional trigger line, and up to six samplers can be deployed on a single trigger lines with an electronic or pneumatic trigger, depending upon sampling depth. In most cases, however, sample volume requirements can be reduced by working closely with the analytical laboratory, and sample volume is expected to become less of an issue with time as analytical methods improve.

While the volume of samples collected using low-flow purging and sampling typically is not limited (as long as there is adequate flow in the well), several other passive samplers have similar volume limitations (especially the RPP sampler). Again multiple samplers can be deployed to circumvent this problem, and some samplers (e.g., the RGC sampler and the HydraSleeve sampler) can be made in longer lengths to accommodate larger sample volume requirements.

3.0 PERFORMANCE OBJECTIVES

The primary objectives for this demonstration/validation project were to show that the Snap Sampler passive groundwater sampling technology can provide 1) technically defensible analytical data for a number of VOCs and inorganic analytes and 2) substantial cost savings. At each well, samples were collected with 1) the Snap Sampler, 2) low-flow purging and sampling (EPA Region 1, 1996), and 3) the RGC sampler. The performance objectives that were used to determine if the primary objectives were met are outlined in Table 3-1 for the Snap Sampler and Table 3-2 for the RGC sampler. These tables include both qualitative and quantitative measures of the performance of the sampling technologies.

Table 3-1. Performance objectives for the Snap Sampler.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative			
1. Ability to sample a range of contaminants at site	*Adequate sample volume for all analyses*	*Similar detection capabilities (as with low-flow sampling)*	Yes
2. Reproducible data	*Analyte data for replicate samples*	*Among replicate samples, a % RPD of 25% or less, or equal to or better than that for low-flow samples*	Generally Yes; Issues for some total metals with Snap Sampler ***and low-flow sampling***
3. Agreement between sampling methods for analytes of interest	*Analyte concentrations for each sampling method for all wells*	• *Lack of statistically significant differences* • *Lack of bias*	Yes, with two exceptions (total Fe and total Mn)
4. Reduced sampling time	*Field records of activities at each well*	*Less time needed to sample a well*	Yes
5. Less costly sampling method	• *Records of the costs for equipment and supplies* • *Field record of technician's time*	*Cost savings of at least 25%*	Yes
Qualitative			
1. Ease of use	*Field records of activities at each well*	*Technician able to learn the procedure with relative ease.*	Yes
2.Ease of use	*Field records of activities at each well*	*Few problems requiring second attempt to sample the well*	Yes (providing manufacturer's directions were followed)
3. Ease of Use	*Feedback from field technician*	*Operator acceptance*	Yes

Table 3-2. Performance objectives for the RGC sampler.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative			
1. Ability to sample a range of contaminants at site	*Adequate sample volume for all analyses*	*Similar detection capabilities (as with low-flow sampling)*	Yes, but ***not*** able to sample for total inorganic analytes
2. Reproducible data	*Analyte data for replicate samples*	*Among replicate samples, a % RPD of 25% or less, or equal to or better than that for low-flow samples*	Yes, with one exception
3. Agreement between sampling methods for analytes of interest	*Analyte concentrations for each sampling method for all wells*	*• Lack of statistically significant differences* *• Lack of bias*	Generally yes, exceptions for 2 VOCs and for 4 dissolved inorganics
4. Reduced sampling time	*Field records of activities at each well*	*Less time needed to sample a well*	Yes
5. Less costly sampling method	*• Records of the costs for equipment and supplies* *• Field record of technician's time*	*Cost savings of at least 25%*	Yes
Qualitative			
1. Ease of use	*Field records of activities at each well*	*Technician able to learn the procedure with relative ease.*	Yes very easy to use
2.Ease of use	*Field records of activities at each well*	*Few problems requiring second attempt to sample the well*	Yes
3. Ease of Use	*Feedback from field technician*	*Operator acceptance*	Yes

3.1 ABILITY TO YIELD QUALITY DATA

The most important objective was to determine if these passive sampling methods, especially the Snap Sampler, yielded quality, defensible data. There are several ways to determine this. All of these metrics were quantitative. First, the sampling method must be useful for a range of contaminants at the site by providing adequate sample volume for the analyses so that the detection capabilities (or sensitivity) of the sampling method is similar to that of low-flow sampling. In all cases, the Snap Samplers provided adequate sample volume for the analyses of the various analyte types in this study. Thus, the sensitivity of the analyses was the same for the Snap Sampler and low-flow sampling. In con-

trast, only samples for the analyses of VOCs and dissolved inorganics could be collected with the RGC sampler (because this sampler collects filtered samples). However, the RGC sampler provided adequate sample volume for the analyses of these analytes, and thus comparable sensitivity with low-flow sampling.

The method should yield data that are reproducible. That is, when field replicate samples are taken, the Relative Percent Difference (RPD) should be 25% or less, or should be equal to, or better than, that for low-flow samples for analytes where the concentrations were greater than or equal to three times the reporting limit. These findings are discussed in detail in the *Sampling Results* section. However, except for a few exceptions, the replicate data were within the guidelines for the three sampling methods for the VOCs, dissolved inorganics, and total non-metal ions. This was not the case, however, for the total metals from the Snap Sampler and low-flow sampling (total metals were not measured in the RGC samples). The RPD exceeded the guideline for both the Snap Sampler and low-flow sampling for Cr, Fe, and Mn. This was also true for Co, Cu, and Mo but concentrations were at or near the detection limit for these analytes. The RPD also exceeded the guideline for V with the Snap Sampler. The implication of these findings is discussed in more detail later in this report.

Also, there should be good agreement between analyte concentrations for the passive and low-flow sampling methods. That is, concentrations of the analytes in samples taken with the Snap Sampler were similar to those taken using low-flow sampling, and those taken using the Snap Sampler were similar to those taken using the RGC sampler, and those taken using the RGC sampler were similar to those taken using the low-flow sampling. Equivalency can be determined by a lack of statistically significant differences between the test methods using either a paired *t*-test (or its non-parametric equivalent) or a Repeated Measures Analysis of Variance test (RM-ANOVA) (or its non-parametric equivalent). However, it is important to remember that the true accuracy of the low-flow sampling, or any sampling method, is not known. Each of these sampling methods attempts to determine the analyte concentrations differently. The findings from this demonstration will be used to better define the appropriate use of each passive method. In some cases, the passive method may actually provide better information about a site than the conventional method.

Good agreement between the sampling methods can also be determined by seeing if there is a lack of bias between the low-flow and each of the passive sampling methods. A lack of bias can be determined by using a linear regression of the passive sampler data (for each analyte and sampler separately) vs. the low-flow data to determine if the slope of the line is significantly different from 1.0. A slope of 1.0 indicates that there is no significant bias between the two data sets, i.e., there is a one to one correlation between the concentrations for the two methods.

Generally, there was excellent agreement between analyte concentrations in the Snap Sampler and low-flow sampling and these relationships were linear with the slopes equal to 1.0. There were no statistically significant differences between analyte concentrations in the Snap Sampler and the low-flow sampling for the VOCs, dissolved inorganics, total

non-metal anions, and most of the total metals and metalloids. The exceptions to this were for total Fe and total Mn. While concentrations of Fe were at or near the detection limit in most of the wells where precision is the poorest, concentrations of Mn were significantly higher in the Snap Sampler samples.

For the RGC sampler, only concentrations of VOCs and dissolved inorganics could be compared because this sampler is not able to provide unfiltered samples. For the VOCs, there was a statistically significant difference for two of the four analytes, MTBE and TCE. MTBE concentrations were higher in the RGC sampler (than in the low-flow samples) while TCE concentrations were lower. There was good agreement between the concentrations of dissolved As, Ca, Cr, Ni, and V. However, concentrations were slightly significantly higher for Ba, Mg, K, and Na in the RGC sampler. Again this is discussed in more detail later in this report.

3.2 LESS COSTLY SAMPLING METHOD

The other primary objective of this demonstration was that the sampling method be less costly than low-flow purging and sampling. This objective includes two quantitative performance objectives: 1) to reduce sampling time, and 2) to reduce sampling costs by 25%. To determine whether these criteria were met, accurate records of all the expenses associated with the equipment and supplies and of the technician's time had to be kept for each of the sampling methods. Both sampling methods yielded reduced sampling (greater than 25%) and reduced sampling costs by more than 25%.

3.3 EASE OF USE

Another measure of the performance of the passive samplers included ease of use, which was more qualitative. Ease of use was determined by the following:1) Was the technician was able to learn the procedure relatively easily? 2) Were there few problems that resulted in having to sample the well more than once? 3) Was the sampler generally accepted by the operator? The first two of these criteria were determined from sampling records in the field notebook. Operator acceptance was determined from feedback from the field technician. Both sampling methods were found to be relatively easy to use.

4.0 SITE DESCRIPTION

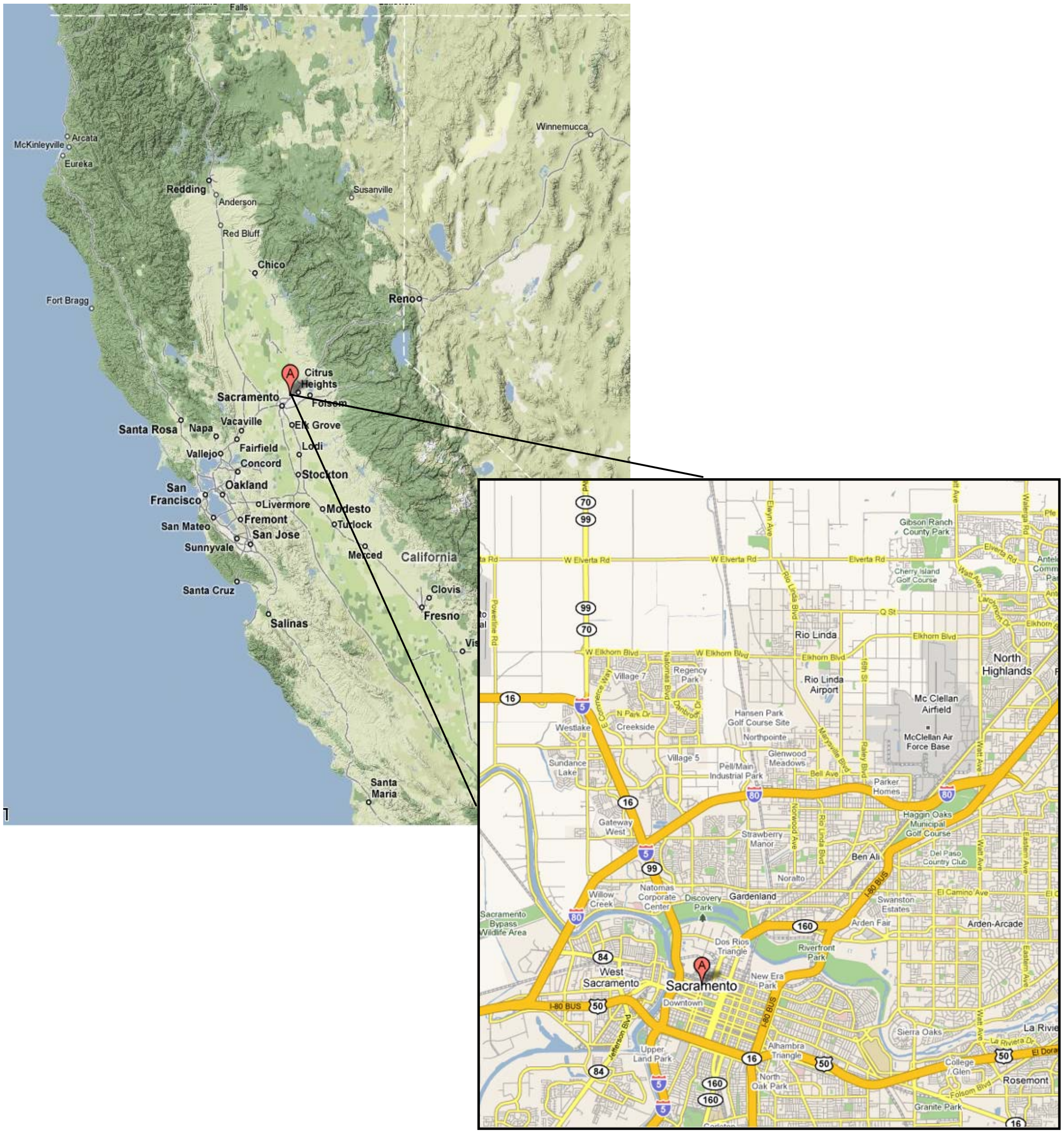


Figure 4-1. Location of the former McClellan AFB (adapted from Google 2009).

The former McClellan Air Force Base (AFB) is located approximately 7 miles northeast of downtown Sacramento, CA, and occupies approximately 2952 acres (Fig. 4-1). The base is approximately bounded by Elkhorn Boulevard on the north, Roseville Road on the south, Watt Avenue on the east, and Raley Boulevard on the west. The base includes 107 maintenance buildings and 200 shops (Fig. 4-2). Figure 4-3 shows an aerial view of the base. The areas to the north, east, and south of the base are densely populated.

Figure 4-2. Location of the former McClellan AFB (adapted from a figure in Parsons 2004).

Figure 4-3. Aerial photograph of the former McClellan Air Force Base and surrounding areas.

4.1 SITE LOCATION AND HISTORY

The former McClellan AFB was originally established in 1936 as an aircraft repair depot and supply base for the War Department. During World War II, the base became a major industrial facility, serving as a bomber and cargo aircraft maintenance depot, and in the early 1950s it was transformed into a jet fighter maintenance facility. Through most of its operational history, the base was engaged in a wide variety of operations involving the use, storage, and disposal of hazardous materials. Hazardous materials that were used included industrial organic solvents, caustic cleaners, electroplating chemicals, metals, polychlorinated biphenyls (PCBs), low-level radioactive wastes, and a wide variety of fuel oils and lubricants. Historical waste disposal practices included the use of burial pits for the disposal or burning of these materials (CH2M Hill 1994). The base is divided into eight major operable units (OUs) with two units subdivided, which extend from the ground surface to the watertable (Fig. 4-4). The groundwater OU differs from the other 10 vadose-zone OUs in that it spans the entire base and extends from the watertable down to the base of the aquifer.

Groundwater contamination at the base has been under investigation since 1979, with a groundwater treatment system, air stripping with thermal oxidation, coming on-line in the early 1980s (CH2M Hill 1994). The cleanup effort is the largest in the Air Force. A total of 318 sites have been identified with numerous remedial investigation/feasibility studies (RI/FS) conducted within the 10 vadose-zone OUs.

A groundwater preliminary RI was conducted by Radian in 1992. In the mid 1990s, two interim actions were initiated to remove solvents from the subsurface and to minimize further migration of the solvents away from their source areas. These included a 1993 removal action to install a number of soil vapor extraction (SVE) systems and a 1995 Groundwater Interim Record of Decision (IROD) to install extraction wells on and off-base to contain VOC-contaminated groundwater plumes. McClellan was placed on the AFB closure list in 1995 and a feasibility study of the groundwater OU was prepared in 1999 with a Proposed Plan issued in 2000. Under BRAC IV, McClellan AFB was officially closed as an active military base in July 2001. In 2004 a GW OU Addendum FS focused on VOCs was conducted. A revised Proposed Plan was issued in 2004 as well as the IROD. In late summer of 2006 the base and USEPA agreed that the current IROD of 1995 would be the final ROD for the groundwater OU for VOCs in combination with SVE. This Final ROD was signed in August of 2007. Computer modeling suggests the cleanup will be completed in 55 years.

A non-VOC groundwater ROD is in development with a remedial investigation started in 2006. A site investigation (SI) was completed in 2006 and a RI/FS in 2008, which identified 1,4-dioxane, perchlorate, and hexavalent chrome as contaminants of concern. A Proposed Plan was completed in 2009.

Two different approaches are currently being used to address the contamination at the base: the traditional Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) approach and the privatized cleanup approach. The traditional CERCLA approach at the base involves the Air Force investigating the sites, determining the

nature and extent of contamination in soil and groundwater, evaluating the risk, preparing a ROD to document the selected remedial action, and then designing and conducting the remedial actions. Most sites are following this approach. The privatized cleanup approach was undertaken for the first time in August 2007 at Parcel C-6, a 62-acre site contaminated with polychlorinated biphenyls (PCBs). The privatized cleanup approach involves deeding the land to a private party before cleanup of contamination is complete. The private party will use money provided by the Air Force to complete site investigation and cleanup under the direction of USEPA and state regulators.

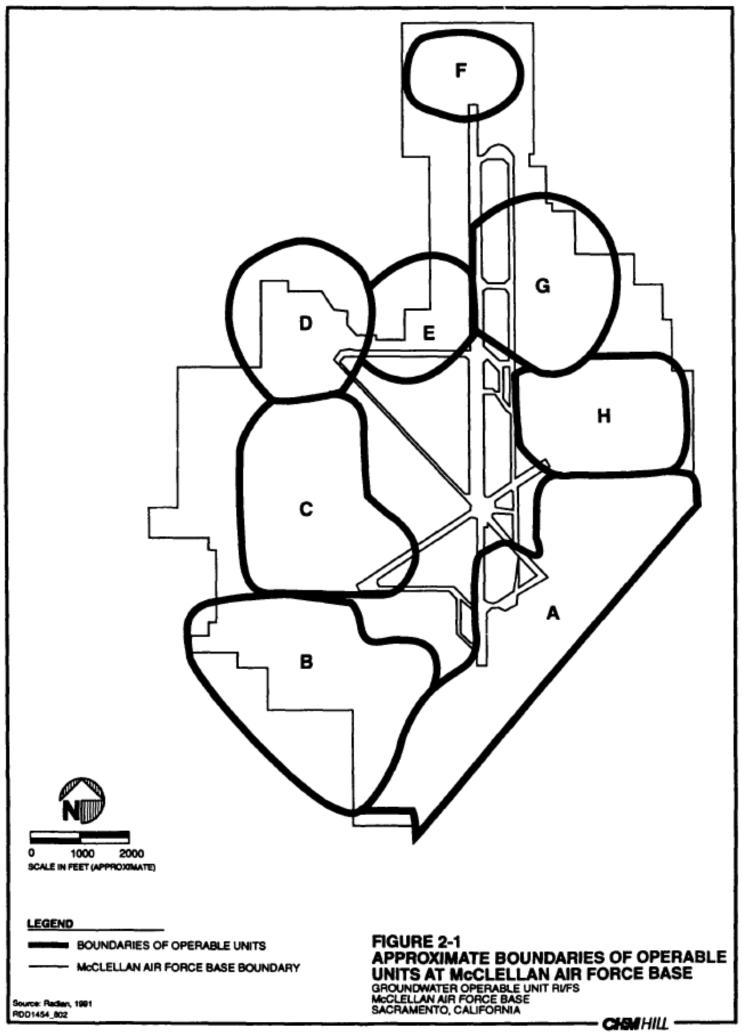


Figure 4-4. Approximate boundaries of operable units at the former McClellan Air Force Base, excluding the groundwater operable unit. Note operable units A and B each have been split into two sub-operable units.

4.2 SITE GEOLOGY /HYDROGEOLOGY

The former McClellan AFB is located in the Central Valley, which extends approximately 120 miles north of Sacramento to Redding, CA, and about 400 miles south to Bakersfield, CA. The Great Valley is approximately 40 miles wide, and is divided into the Sacramento Valley (north of the confluence of the Sacramento and San Joaquin Rivers) and the San Joaquin Valley (south of the confluence). The Great Valley is bordered by the Sierra Nevada range on the east and the mountains of the Coastal Ranges on the west.

The base is located on an alluvial plain forming the eastern side of the Sacramento Valley. The plain is nearly flat, and is dissected by numerous westerly trending streams that drain the Sierra Nevada. The American and Sacramento Rivers are the major drainages for the area near the base and are fed by local creeks such as the Magpie, Don Julio, Robla, Rio Linda, and Arcade. The drainage patterns of some of these creeks have been modified within the base boundary for buildings, runways, and roads. Magpie Creek has undergone the most extensive changes since the base opened. The land surface gently slopes from east to west, exhibiting little topographic relief. Ground surface elevations range from approximately 75 ft above mean sea level (AMSL) on the eastern side to approximately 50 ft AMSL on the western side.

The base experiences a moderate climate, with mild winters and hot, dry summers. Average daily maximum temperatures range from 53 to 54°F in January to 93 to 98°F in July (University of California, Berkeley, undated). Mean annual precipitation from 1875 to 1975 near the Base is approximately 24 in. (Kahrl 1979). Approximately 90% of the rainfall occurs between November and April with little or no precipitation from late spring to early fall. Most of the rainfall is associated with Pacific storms, which are frequent in winter (National Oceanic and Atmospheric Administration [NOAA] 1989).

4.2.1 Geology

In general, the sediments in the upper few hundred feet of the subsurface beneath McClellan AFB consist of coalescing deposits laid down by alluvial and fluvial systems of various sizes and competence that flowed generally from northeast to southwest or west. Sediments are primarily sand, silt, and clay, generally poorly sorted, with localized occurrences of gravel, generally in the southern part of the base. The nature of fluvial deposition, including stream meandering and abandonment/reoccupation of channels, produced morphologically irregular lenses and strata that are laterally and vertically discontinuous. The coalescing and intercalating nature of the sediments makes distinction between units (or stratigraphic correlation over distances greater than a few tens of feet) difficult. Individual lithologic units rarely extend laterally for more than 50 ft. Thus, interpretation must be based on examination of drive samples or geophysical logs from boreholes (CH2M Hill 1994). In addition, meandering and abandonment of channels has produced complex site stratigraphy, dominated by lenses of material with little lateral or vertical continuity (CH2M Hill 1994).

The shallow, marine embayment, salt-bearing Chico Formation overlies much of the Sierran basement rock underlying the valley. The basement rock lies at a depth of over

600 ft below ground surface (BGS) (Radian 2001). The Ione Formation is a transition zone between marine and non-marine deposits, exemplified by sandstone and peat-rich clay beds. The Ione Formation is generally thought to be non-water-bearing, but contains water of brackish quality, indicative of saltwater diluted by freshwater. The overlying Valley Springs Formation consists of weathered ash from volcanic eruptions, forming low permeability clay with some sand and gravel. The Valley Springs Formation is also considered non-water-bearing. At McClellan AFB the Chico, Ione, and Valley Springs Formations are generally grouped and referred to as pre-Mehrten sediments. These units are thought to underlie the site at depths exceeding 600 ft BGS (California Department of Water Resources 1974).

The Mehrten Formation is generally divided into two units: a lower non-water-bearing, low permeability, tuff breccia and upper water-bearing andesitic black sands. The black sand unit is known for producing large quantities of good to excellent quality groundwater (California Department of Water Resources 1978). According to well data, this unit is believed to underlie the site at a depth of approximately 200 ft BGS (Radian 1992).

Three units overlie the Mehrten Formation in the vicinity of McClellan AFB: Laguna, Turlock Lake, and Riverbank Formations (Radian 1992). The Laguna Formation is the transition from volcanic to continental granitic and metamorphic deposits and consists of feldspathic silt, clay, and sand deposits with occasional hardpan deposits. The feldspar has typically weathered to clay. The tan or “white” clay or micaceous layers serve as marker beds for this formation. The Laguna Formation ranges in thickness from 125 to 200 ft (California Department of Water Resources 1974).

The Turlock Lake Formation is similar to the underlying Laguna Formation, except feldspars tend to be less weathered. The contact between the two is thought to be an erosional unconformity indicating up to 30 ft of relief at the time of deposition (Radian 1990); however, the two units are often difficult to distinguish. The Turlock Lake formation consists of arkosic fine sand clay which coarsens upwards (Radian 2001). The thickness of the Turlock Formation varies from 0 to 225 ft (California Department of Water Resources 1974).

The Riverbank Formation is composed of feldspathic sediments deposited in a fluvial or alluvial environment. The sediments consist of sand interbedded with fine sand and silt with some pebble and gravel lenses. Typically, the Riverbank Formation has better water-bearing characteristics than the Laguna or Turlock Lake Formations, making it an important unit for shallow irrigation wells. Overlying the Riverbank Formation is soil, which averages several feet in depth.

4.2.2 Hydrogeology

The groundwater system in the vicinity of McClellan AFB has been divided into two zones: an upper zone composed of the Laguna, Turlock Lake, and Riverbank Formations and a lower zone composed of the Mehrten Formation and underlying water-bearing formations (California Department of Water Resources 1974). The two zones are separated by a buried erosional surface of moderate to high relief. Most groundwater production

wells in the area are screened in the Mehrten Formation (Engineering Science 1983). Groundwater recharge in the eastern portion of the Sacramento Valley occurs as a result of leakage from streams and rivers, percolation of precipitation and irrigation water through soils, and migration of runoff along fracture zones and formation contacts in the foothills of the Sierra Nevada. The upper water-bearing zone in the Sacramento Valley is recharged predominantly through percolation of water from the ground surface, although this process is generally inhibited by the presence of hardpan throughout much of the valley.

The aquifer system at the base has been divided into a series of monitoring zones for investigations. The monitoring zones were defined based on stratigraphy derived from geophysical logs and are designated A through F, from shallowest to deepest (Fig. 4-5). The wells to be included in this demonstration are completed in the A, B, or C zones. Zones A and B are younger and extremely heterogeneous, and were deposited by low energy fluvial deposits. Zone A typically extends from the ground surface down to a depth of approximately 50 to 75 ft BGS. Zone A sediments have a lower permeability than the other zones. Zone B extends from the base of Zone A to a depth of approximately 125 to 140 ft BGS. Zone C is older and consists of generally coarser grained sediments (sands and gravels) that were deposited by higher energy fluvial erosional deposits (CH2M Hill 1994). Zone C extends from the base of Zone B to a depth of approximately 200 to 240 ft BGS. Deposits generally show a greater degree of heterogeneity in the northwest portion of the base, with some deposits showing extreme variation over distances less than 25 ft (Radian 1993). Deposits in the southeast portions of the base are more persistent in both vertical and lateral extent.

The transmissivity of Zone A ranges from 300 to 16,000 gallons per day per foot (gpd/ft) using the Jacob Method, 100 to 28,000 gpd/ft using the Theis Recovery method, and 300 to 7200 gpd/ft using the Papadopulos-Cooper method (Radian 2001). Similarly, results of pumping tests using the Jacob method suggest the transmissivity of Zone B ranges from 3800 to 20,000 gpd/ft, while the Theis Recovery method suggests a range from 4000 to 17,000 gpd/ft, and the Papadopulos-Cooper method suggests a range from 1000 to 5000 gpd/ft. The transmissivity of the C zone was estimated to range from 1600 to 87,000 gpd/ft using the Jacob method, 3500 to 58,000 gpd/ft using the Theis Recovery method, and 1800 to 16,300 gpd/ft using the Papadopulos-Cooper method. These tests indicate Zone A is unconfined and the lower zones behave as a semi-confined to confined aquifer.

The watertable in the vicinity of the base is typically between 90 to 110 ft BGS. Currently, the general direction of groundwater movement beneath the base is from north to south, although locally the direction of groundwater movement is influenced by water-supply wells, and by groundwater extraction and treatment systems (Radian 2000).

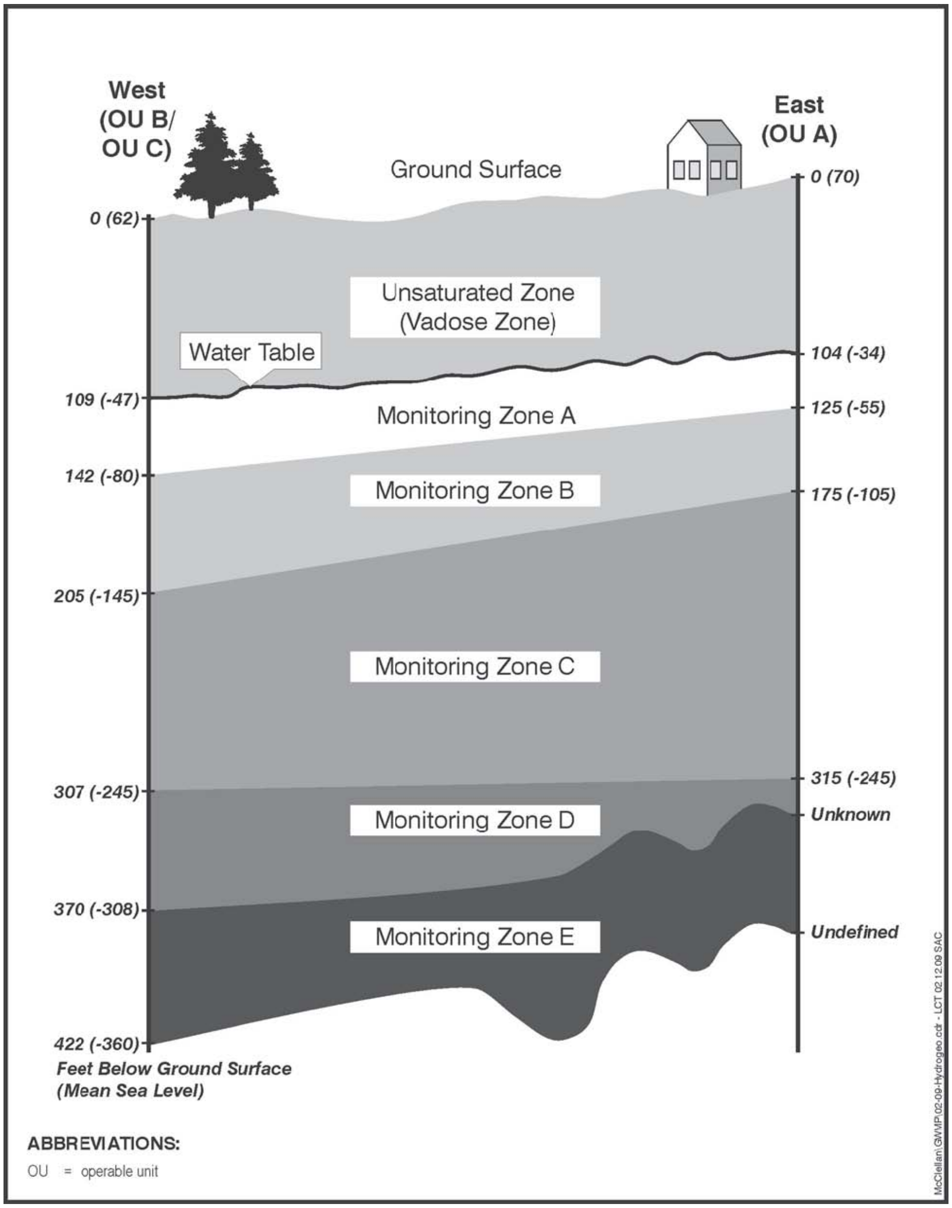


Figure 4-5. Generalized Hydrogeologic Cross-Section for the former McClellan AFB (from URS 2009).

Variations in the depth to water depend predominantly on local topography and locations of cones of depression from high-capacity extraction wells. The elevation of the water-table displays natural fluctuations on the order of about 2 ft per year. From approximately 1955 to 1995, watertable elevation declined on the order of 1 to 2 ft per year as a result of groundwater withdrawals for agricultural, municipal, industrial, and domestic uses (Radian 1986, 1987, 2000). Since then, the watertable has stabilized owing to decreased groundwater extraction rates and water conservation efforts (Parsons 2004).

Extensive groundwater pumping near McClellan AFB has also altered the flow direction of the local groundwater system. In 1955, groundwater flow was generally to the south-west toward a pumping depression southwest of the base. By 1965, this depression had

deepened, and a second pumping depression developed directly south of the base as a result of the operation of production wells located *near* the base boundary. Flow directions were therefore altered as groundwater on the base began to flow to the south and groundwater west of the base began to flow in an east-southeast direction in the late 1950s or early 1960s (Radian 1986). Flow directions were further modified by the installation of 103 groundwater remedial extraction wells on base. Groundwater flow for contamination on the west side of the base is southward and flow on the eastern side of the base is southeastward.

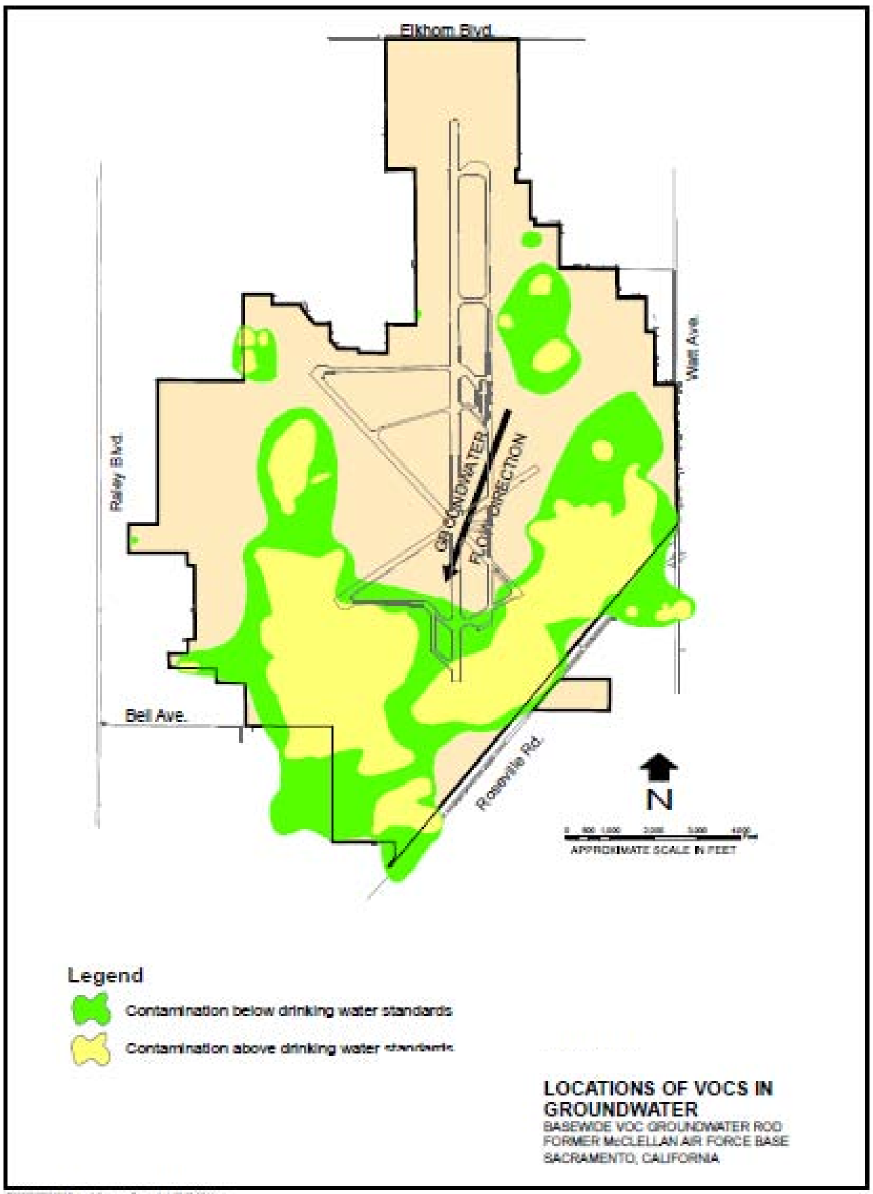


Figure 4-6. Extent of volatile organic compound contamination in groundwater at McClellan Air Force Base (adapted from Parsons 2004).

4.3 CONTAMINANT DISTRIBUTION

Trichloroethene (TCE), tetrachloroethene (PCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), 1,1-dichloroethene (1-1-DCE), and carbon tetrachloride are the predominant contaminants of concern (COC) in groundwater but there are eight other VOCs with reported concentrations above maximum contaminant levels (MCLs). Although, numerous source areas exist, there are three primary areas with VOC groundwater contamination: 1) west side of the airfield, 2) east side of airfield, and 3) an isolated area northeast of the airfield. The source terms on the east and west portion of the base have coalesced into two broad areas of contamination with the plumes extending southward. The contaminant having the greatest spatial extent is TCE, which underlies approximately 520 acres or 18% of the base and an additional 70 acres off base using the Federal drinking water standard of 5 µg/L (Fig. 4-6). Contamination is principally confined to the uppermost groundwater zones beneath the base, but has been detected to a depth of 390 ft (CH2M Hill 1994).

5.0 TEST DESIGN

The objectives for this demonstration/validation project were to show that the Snap Sampler passive groundwater sampling technology can provide 1) technically defensible analytical data for a number of VOCs and inorganic analytes and 2) substantial cost savings. The former McClellan AFB was selected as the second test site for this demonstration. Analytes that were sampled at this test site included VOCs, and several inorganic analytes, including metals and some anions. Specifically, the VOCs at this site included TCE and various daughter products. Metals and metalloids that were found at this site included Al, As, Ba, Ca, Cr, Co, Cu, Fe, Mg, Mn, Mo, Ni, K, Na, V, and Zn. Other anions that were found at this site included sulfate and chloride. This was the first time our laboratory has sampled for multiple types of analytes using the Snap Sampler.

Ten monitoring wells were selected for this study. At each monitoring well, samples were collected with 1) the Snap Sampler, 2) low-flow purging and sampling (USEPA Region 1, 1996), and 3) the Regenerated Cellulose (RGC) Sampler (also known as the Dialysis Bag Sampler). Samples that were collected were analyzed for VOCs and inorganic analytes. For the inorganic analytes, both field-filtered and unfiltered samples were collected. The intent of having both filtered and unfiltered Snap Sampler and low-flow samples and (naturally filtered *in situ*) RGC samples was to compare dissolved and colloidal-borne metal species under pumped and passive conditions.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

Our initial hypothesis was that there were no statistically significant differences between the analyte concentrations in the samples taken with the various sampling methods. That is, concentrations of the analytes in samples taken with the Snap Sampler are similar to those taken using low-flow sampling, and those taken using the Snap Sampler are similar to those taken using the RGC sampler, and those taken using the RGC sampler are similar to those taken using the low-flow sampling. However, when conducting these comparisons, it is important to realize that it is not known whether low-flow sampling, or any sampling method, provides samples that accurately represent the analyte concentrations in the geological formation or in the well. Each of these sampling methods collects a sample differently and, thus, may yield different information. It is our hope that the findings from this demonstration and other recent studies will be used to better define the appropriate use of these methods.

5.2 EXPERIMENTAL CONTROLS

For the statistical analyses (that will be used to compare the three sampling methods) to be as robust as possible, it was important to minimize any extraneous factors that could influence the data quality. These factors included the following:

- Improperly functioning wells, i.e., inadequately developed wells.
- Flow patterns within the wells, e.g., known vertical flow within the well.
- Known contaminant gradients in the well.
- Differences in sampling depth of samplers.

- Flow induced changes caused by a sampler.
- Contaminant concentrations that are too low to measure.

To address these concerns, we included the following provisions in the design of this demonstration in an effort to reduce the impact of the above factors:

- Selecting wells that are currently part of an active monitoring network, reducing the possibility of poorly functioning wells.
- Selecting wells with known detectable concentrations of constituents of concern.
- Selecting wells with historic data that indicate little if any vertical stratification within the wells, and then testing the wells for vertical flow.
- Matching sampler depth with pump intake for low-flow sampling.
- Carefully selecting a sampling order that reduces sampler impacts on subsequent sampling events.

5.3 BASELINE CHARACTERIZATION

Before sampling the wells for chemical analyses, the ambient vertical flow was determined in 7 of the 10 wells. Ambient vertical flow is defined as measurable vertical flow within the well under static, non-pumping, conditions at the well and other nearby wells. Ambient vertical flow testing determines whether chemical data would be affected by over-weighting, or under-weighting, from ambient vertical flow from a more permeable zone. Elci et al. (2001, 2003) illustrated that ambient vertical flow can change water contribution to the well—under both ambient and subsequent pumped conditions. Testing under this program required sampling by both passive and pumped methods. Therefore, it was deemed prudent to test the potential for artifacts caused by vertical flow. Ambient vertical flow was measured at several depths within the screen in each of the wells selected for chemical testing at McClellan.

Vertical flow testing was conducted using an electromagnetic flow meter tool manufactured by Century Geophysical Instruments of Tulsa, OK. The tool consists of a downhole probe lowered via a winch to a known position. The tool's sensor system consists of an electrical current sensor designed to measure current generated by movement of a conductor through a magnetic field. The water itself is a conductor and ambient vertical movement of that water through the magnetic field inside the tool generates a small measureable current. The current generated by flow is proportional to the flow rate through the tool. The flow meter software reports the flow rate in liters per minute (Lpm). Calibrations to "no vertical" flow were conducted in the blank casing of each well. The calibration was conducted to establish a baseline "no-flow" condition.

We had problems with both the software and hardware (of this flow meter) during the course of the investigation. Several days were needed to accommodate functional problems associated with software compatibility, clarity of the instruction package, and a vendor-supplied laptop. Should a reader select this approach to conduct flow meter testing, we recommend one or two days of practice prior to field mobilization.

At each well, the flow meter tool was deployed above the screen interval using the winch provided with the tool rental. The electronically controlled winch displayed depth of the measuring point at a precision of 0.01 ft. Therefore, the tool sensors were positioned fairly precisely.

The tool was left to equilibrate in the saturated blank casing of each of the wells for 5–10 minutes. This equilibration time was included to allow the water level in the well to re-establish equilibrium after the positive displacement (slug) from inserting the tool. Following equilibration, we conducted test readings of the flow meter tool. Several readings were collected in the blank casing to determine consistency of the results. The tool was then lowered into the screen interval of the wells and measurements were taken approximately every 2 ft.

These flow data will detect ambient vertical flow. This information can be used to see if a specific vertical zone in the well (e.g., upper vs. lower half) should be expected to be over-weighted in its contribution of water to the well. For example, if downward vertical flow is found, the upper portion of the well would be the only portion actually monitored during passive sampling, and that zone would be over-weighted during pumping. This information can be used to assist in interpretation of results from the chemical testing portion of the study.

Ambient (non-pumping) flow test data indicated *no detectable vertical flow in any of the seven wells tested at McClellan*. Table 5-1 presents the results from the ambient flow testing.

Table 5-1. Ambient (non-pumping) flow testing results.

Well	Date	Screen*	Vertical Flow
MW-72	6/25/08	129-139	None detected
MW-333	6/26/08	158-168	None detected
MW-400	6/26/08	111-121	None detected
MW-225	6/26/08	157-167	None detected
MW-136	6/27/08	230-245	None detected
MW-173	6/27/08	156-166	None detected
MW-437	6/27/08	160-170	None detected
MW-427	--	124-134	Not tested
MW-211	--	150-160	Not tested
MW-1065	--	120-130	Not tested

* Measurements in feet below top of casing

5.4 TREATABILITY OR LABORATORY STUDY RESULTS

The results from previous laboratory studies (Parker and Mulherin 2007; Parker et al. 2009) were given in the *Technology Development* section. No new treatability or laboratory studies were conducted for this demonstration.

5.5 DESIGN AND LAYOUT OF TECHNOGY COMPONENTS

5.5.1 Site Layout and Monitoring Wells

Ten 4-in. diameter monitoring wells on the former McClellan AFB were selected for this field study. Nine of the wells had PVC casing with stainless steel screen. The tenth well was constructed with low-carbon casing and screen. The criteria used to select these wells included a 4-in. well diameter (the wells needed to be large enough to accommodate several pieces of sampling equipment at the same time; this would normally not be a requirement for any one of the sampling devices used in this study), screen length, sampling depth, and detectable concentrations of the analytes of interest. Analytes of interest included VOCs, metals, and two anions (sulfate and chloride). For each well, samples were collected using the Snap Sampler, the RGC sampler, and low-flow purging and sampling (USEPA Region 1 1996). Table 5-2 includes information on the screen depth, depth of the watertable, and analytes of interest for each of these wells. Figure 5-1 shows the location of the wells on the former AFB.

Table 5-2. Information on the monitoring wells used at the former McClellan AFB.

Well #	VOC[1]	1,4-dioxane	Metals[2]	Hexavalent Chromium	Anions[3]	Depth to watertable (ft btoc)	Top of screen (ft bgs)	Bottom of screen (ft bgs)	Screen length (ft)
MW-72	X	X	X		X	103	121	131	10
MW-136	X	X	X	X	X	102	230	245	15
MW-173	X		X	X	X	115	156	166	10
MW-225	X		X	X	X	114	157.6	167.6	10
MW-211	X		X	X	X	109	151	161	10
MW-333	X		X	X	X	112	160	170	10
MW-400	X		X		X	105	111	121	10
MW-427	X		X		X	108	114	124	10
MW-437	X		X	X	X	110	160	170	10
MW-1065	X		X	X	X	112	121	131	10

1 VOCs include TCE and daughter compounds.
[2] Metals typically found at McClellan in concentrations sufficiently high enough to allow statistical analyses include: Al, As, Ba, Ca, Cr, Co, Cu, Fe, Mg, Mn, Bo, Ni, K, Na, V, and Zn.
[3] Anions include sulfate and chloride.

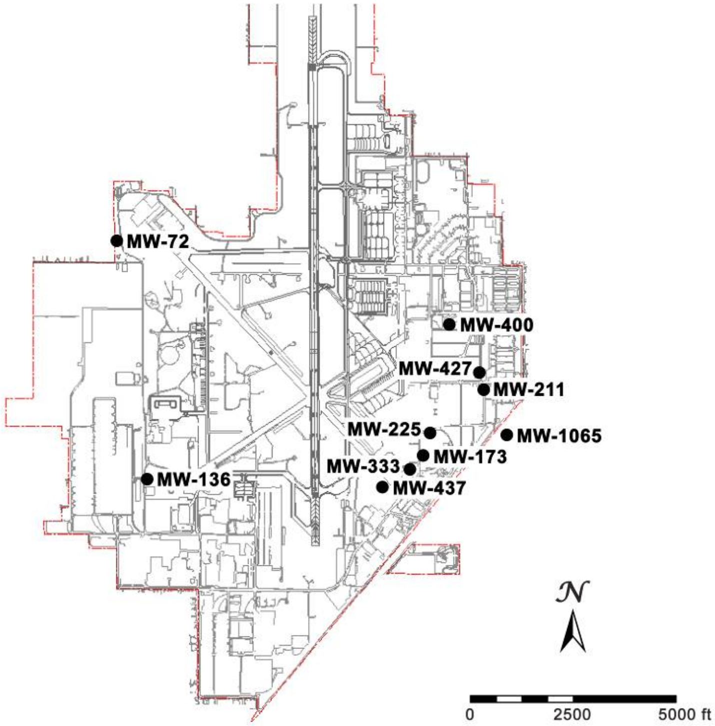


Figure 5-1. Base map showing the location of the monitoring wells. (Figure adapted from Parsons 2005 by J. Mason 2009.)

5.5.2 Sampling equipment and preparation

5.5.2.1 Bladder pumps and purging equipment

All of the monitoring wells in this study contained dedicated bladder pumps that were used for routine sampling at this site. These pumps were 1.66-in. OD (4.2-cm) PVC QED Well Wizard bladder pumps (model no. P1101M) with Teflon-lined PE tubing. With the exception of turbidity, the purge parameters were monitored using a Horiba (MDL W-22XD) probe using a flow-through cell. These included dissolved oxygen (DO), conductivity, salinity, pH, total dissolved solids (TDS), redox potential (ORP), and temperature. Turbidity was monitored using a LaMotte 2020 Turbidimeter (Chestertown, MD).

5.5.2.2 Snap Samplers

Snap sampler equipment (ProHydro, Inc.; http://www.snapsampler.com/) included 40-mL glass Snap Sampler VOA vials, 125-mL and 350-mL high-density polyethylene (HDPE) Snap Sampler bottles, and acetal (Delrin) plastic Snap Sampler bodies. Because the watertable was quite deep, an electronic trigger mechanism was used.

At the time that we conducted this study, the electric trigger line was covered with a Neoprene jacket[1] that had a definite odor. Because we were concerned that the Neoprene might leach organic or inorganic constituents and because we did not have time to test the trigger line prior to conducting this field study, the trigger line was covered with a layer of low-density polyethylene (LDPE) tubing that was sealed at the top and bottom to prevent the entry of water (shown in Fig. 5-2). The Snap Samplers were deployed according to instructions found in ITRC (2007) and on the manufacturer's web site.

Figure 5-2. Polyethylene covering on electronic trigger line.

5.5.2.3 RGC samplers

Pre-cleaned regenerated cellulose (CelluSep H1) membrane (76-mm flat width, catalog number 0810-76 from Membrane Filtration Products Inc., Seguin, TX) in preservative solution was purchased for this study. The molecular weight cut off for this membrane is 8000 daltons, and the average pore size is 0.0018 µm. To accommodate the sample volume needed for the various analyses, each RGC sampler was 15 in. long.

The RGC Samplers were built just before we left for the field site according to the construction protocol given by the ITRC passive sampler team (ITRC 2007). The support tubing that was placed inside the membrane for support of the samplers was Polypropylene tubing (catalog # RN2020-18, InterNet Inc. of, Minneapolis, MN). The outer protec-

[1] The developer has since changed the material in the electric actuator. The actuator plunger and bottom end is now constructed with a rigid phthalate-free polyurethane, and the material encasing the electric actuator is a semi-rigid phthalate-free material that has been approved by the FDA for contact with food. Both materials have been tested by the developer and were found not to leach metals, VOCs, or SVOCs.

tive mesh was black LDPE Cushionet Mini-Coil (1.5-2-in. width from M-sLine, Cleveland, OH).

After constructing the samplers, we placed them in 1-gal., plastic zip-closure bags filled with DI water, and shipped them on ice in a cooler by overnight courier. Once the samplers arrived at the site, they were placed in a refrigerator and kept there until they were needed.

The ITRC (2007) passive sampling team recommends that RGC samplers be equilibrated in deoxygenated water prior to deployment in wells that are under anaerobic conditions. Therefore, on the night before the samplers were put into the wells, we placed eight RGC samplers in a homemade sparging tank, which consisted of a rectangular polypropylene box with cover, a brass gas fitting, and a polyethylene-tubing, manifold ring to disperse the gas evenly from the bottom of the tank. Bottled distilled water was added to the unit, and the samplers were then weighted down with stainless steel rods so that they were completely immersed in distilled water as shown in Figure 5-3. We surrounded the tank with bags of ice in a large cooler and covered it with bubble-pack and Styrofoam insulation. Nitrogen gas, from a 20-lb cylinder, was then connected and the system was sparged at a low flow rate overnight. The following morning, enough samplers for the morning's work were removed from the tank, placed in a Zip-Loc PE bag containing sparged DI water, the air was squeezed from the bag, and the bag was sealed. The bagged samplers were placed in a portable cooler packed with ice and transported to the field. For the remaining samplers in the sparging unit, the ice was changed in the cooler and the samplers were left to sparge. After lunch, additional samplers were removed from the sparging tank and the nitrogen gas was shut off. At the end of the day, new samplers were placed in the sparging tank, the nitrogen was turned back on, and the process was repeated for the following day.

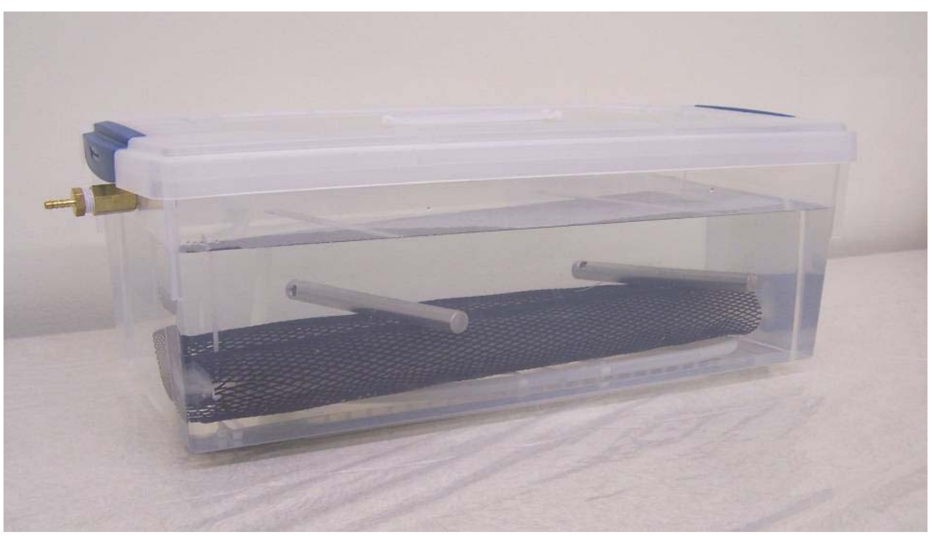


Figure 5-3. Plastic sparging tank with two RGC samplers.

5.6 FIELD TESTING

Early in March, we were informed that there would be a new contract for remediation and sampling on the former base starting 1 July 2008 and that once this contract was in place, we would lose all support from the existing personnel. Therefore, it was essential that we complete all of our sampling by 1 July 2008.

There were four tasks associated with the field work: preparation, deploying the sampling equipment in the wells, sampling the wells, and closure (Table 5-3). Preparation tasks included ordering equipment and supplies, including initiating contracts for the lab analyses and purchasing the Snap Samplers, implementing a contract for the lab analyses, testing the equipment used to monitor purge parameters, making a sparging tank for the RGC samplers, shipping the equipment to the field, and making and shipping the RGC samplers just before we left for the field.

Our primary criteria for analyzing our samples were that the laboratory be: 1) able to conduct the required analyses within the time needed, 2) an EPA NELAC-certified laboratory, and 3) local to the area so that on-site pick up could be arranged. We also preferred to have a laboratory with a proven record.

Our first field trip to the site was to deploy the samplers in the wells. Tasks included setting up our field headquarters in a URS office, buying supplies that were not shipped, purging the RGC samplers with nitrogen gas, and finally deploying the samplers in the wells.

Prior to returning to the site we coordinated our sampling schedule with the laboratory, and tested and calibrated the Hach field colorimeter for analyses of Iron (2). Upon our return to the site, we purchased other needed supplies, calibrated the purge parameter equipment and Hach field kit, sampled the wells and labeled all samples, returned the pumps to the wells, decontaminated the Snap Sampler bodies for shipment home, prepared coolers for pick up by the laboratory courier and completed the chain-of-custody forms, and disposed of purge and other waste water.

After sampling was complete, the RGC samplers were placed in garbage bags and disposed as trash (per guidelines of the site manager). The Snap Sampler bodies were packaged in zip-lock plastic bags so that they could be returned to our laboratory (CRREL) for decontamination. The sampling lines (for the RGC samplers) and the trigger lines and plastic sleeves (for the Snap Sampler) were also placed in garbage bags and disposed of as trash.

The final task was closure that included clean up of the field headquarters, packing the equipment, and shipping it back to our laboratory.

Table 5-3. Field testing tasks.

	Date										
Activity	4/12-4/18	4/19-4/25	4/26-5/2	5/3-5/9	5/10-5/16	5/17-5/23	5/24-5/30	5/31-6/6	6/14-6/20	6/21-6/27	6/28
Task 1 Preparation											
Order equipment, supplies, initiate contract for Snap Samplers, etc.											
Test purge equipment											
Initiate lab contract											
Make sparging tank for RGC samplers											
Ship equipment to field site											
Prep materials for RGC samplers											
Make and ship RGC samplers											
Task 2 Deploy Samplers											
Set up field headquarters, buy supplies											
Purge RGC samplers											
Deploy samplers in wells											
Task 3 Sampling											
Provide lab sampling schedule											
Calibrate/test/ship Hach											
Purchase supplies											
Calibrate field equipment											
Sample wells, ship samples											
Remove & decon equipment											
Dispose of waste water											
Task 4 Closure											
Clean up and ship equipment home											

5.7 SAMPLING METHODS

For each well, whole-water samples were collected using the Snap Sampler and low-flow purging and sampling (USEPA Region 1 1996). These samples were analyzed for VOCs and total inorganics. Additional samples that were also collected using low-flow sampling and the Snap Sampler were filtered in the field and were analyzed for dissolved inorganic species. Having filtered and unfiltered samples allowed us to compare colloidal-borne and dissolved metal species. The samples collected with the RGC samplers were already pre-filtered by the membrane (with a pore size of 18 Å) so these samples were only analyzed for VOCs and dissolved inorganics. The number and type of samples collected during the field demonstration are given in Table 5-4. Additional QA/QC samples were collected and will be discussed later.

Table 5-4. Total number and types of samples collected during field demonstration.

Matrix	Sampler	Number of Samples[1]	Analyte	Location
Groundwater	Snap Sampler	10	Anions	All ten monitoring wells
		10	Dissolved metals	
		10	Dissolved iron	
		10	Total metals	
		10	Total Iron	
		20	VOCs	
	Low-flow sampling	10	Anions	All ten monitoring wells
		10	Dissolved metals	
		10	Dissolved iron	
		10	Total metals	
		10	Total Iron	
		20	VOCs	
	RGC Samplers	10	Dissolved metals	All ten monitoring wells
		10	Dissolved iron	
		20	VOCs	

[1]Does not include QA/QC samples.

5.7.1 Sampler deployment

For each well, the bladder pump was removed and placed on clean plastic sheeting. After this, we bundled the Snap Sampler trigger line, which contained four or five Snap Samplers in series, and one or two RGC samplers to each of the pumps. The samplers were placed so that they straddled (i.e., above and below) the entry port of the bladder pump (Fig. 5-4) and then were tethered to the bladder pump (Fig.5-5). Each Snap Sampler trigger line contained at least two VOA vials and two 125-mL plastic bottles. Additional QA/QC samples will be discussed below.

The equipment was then returned to the well and left to equilibrate for 3 weeks prior to collecting the samples.

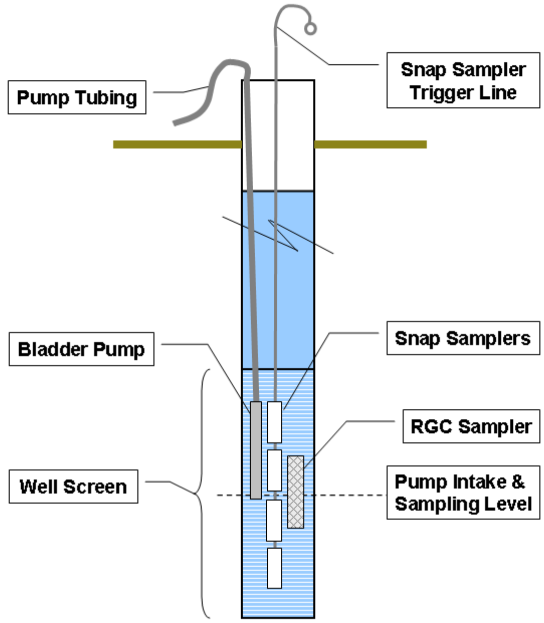


Figure 5-4. Diagram showing the location of the samplers within each well.

Figure 5-5. Tethered sampling equipment being placed in well.

Typically, only four Snap Sampler bottles were placed on a single trigger line. However, in instances where additional samples were needed for QA/QC for metals or anions analyses, a fifth 125-mL Snap Samplers bottle was placed on the trigger line. An extra VOA vial was not needed for QA/QC because there already were two VOA vials on every trigger line. Information on the bottles needed for a regular sampling event is summarized in Table 5-5.

Table 5-5. Summary of bottles needed for a regular sampling event.

Analyte	Snap Sampler	Low-flow	RGC
VOCs	2 40-mL Snap VOA	2 40-mL VOA	2 40-mL VOA
Metals (unfiltered)	60-mL HDPE	60-mLHDPE	---
Metals (filtered)	60-mL HDPE	60-mLHDPE	60-mL HDPE*
Anions	60-mL HDPE	60-mLHDPE	---
Iron (II) (unfiltered)	20-mL HDPE	20-mL HDPE	---
Iron (II) (filtered)	20-mL HDPE	20-mL HDPE	20-mL HDPE*

* Did not have to be field filtered, sampler naturally filtered sample.

5.7.2 Sample collection

The following sampling order was developed to reduce the influence of the various samplers on each other and to minimize the impact of sampling on sample quality.

1. The Snap Sampler was triggered but left in the well.
2. An initial water level measurement was taken using a water level meter.
3. The pump was started and purge, parameters were monitored until they stabilized. Once the purge parameters stabilized, the low-flow samples were collected. The purge parameters that were monitored included turbidity, dissolved oxygen (DO), conductivity, salinity, pH, total dissolved solids (TDS), redox potential (ORP), and temperature. These parameters were monitored until three successive readings did not vary by more than $\pm$ 10% and (preferably) turbidity measurements were below 10 NTU. Water level was periodically monitored to ensure that there was not excessive drawdown in the well during purging and sampling.
4. After the low-flow samples were collected, the Snap and RGC samplers were brought to the surface.
5. Because RGC samplers rely on diffusion and have had days to equilibrate, the time it takes to collect the low-flow samples presumably should not have significantly affected analyte concentrations in these devices. However, because prolonged exposure to air can allow oxygen to diffuse through the RGC membrane and possibly impact analytes that are subject to oxidation/precipitation reactions, and because the Snap Sampler samples remain sealed under *in-situ* conditions during this time, the RGC sample were transferred to a sample bottle before we processed the Snap Sampler samples.
6. Finally, the Snap Sampler samples were handled as described in the next section.

In some instances we did not hear the Snap Samplers snap shut when they were triggered. In these instances, the following sampling order was used. The bundled equipment was removed from the well, the Snap Samplers and the RGC samplers were removed from the bundle, the Snap Samplers bottles were capped to prevent any leakage, and the pumps were returned to the well. The RGC and Snap Sampler samples were then processed as described previously. After allowing the well about 1 hour to recover, we initiated low-flow purging and sampling. This procedure was used in four wells (numbers 136, 225, 437, and 1065).

5.7.2.1 Snap Sampler samples

For the Snap Sampler samples, the Snap Sampler bottles were removed from the Snap Sampler bodies and the bottom caps were placed on all the bottles to prevent any leakage.

The VOA vials were acidified using the method given by the manufacturer: i.e., approximately two drops of a hydrochloric acid (1:1) solution were added to the well in the cap, the septum was then punctured, and then the remaining acid was added until the well in the cap was full, and then the cap was secured.

The contents of one of the 125-mL (or 350-mL) plastic Snap Sampler bottles were transferred directly (i.e., without any filtration) into

- A 20-mL acid cleaned plastic bottle (with no preservative) that was used for field analysis of Iron (2).
- A 60-mL acid-cleaned plastic bottle that contained the acid preservative (1:1 HNO_3) and was used for analyses of total metals.
- A 60-mL acid-cleaned plastic bottle that contained no preservative and was used for the analyses of sulfate and chloride.

The contents from the other 125-mL plastic Snap Sampler bottle were filtered in the field using a membrane filter (described below) and then transferred to

- A 60-mL acid-cleaned plastic bottle, containing the nitric acid preservative, that was analyzed for dissolved metals.
- A 20-mL acid-cleaned bottle (with no preservative) that was used to for the field analysis of Iron (2).

5.7.2.2 RGC sampler samples

To collect a subsample from the RGC sampler, the membrane was pierced with a Pasteur pipet and the stream of sample was emptied into

- 40-mL certified VOA vials containing acid preservative.
- A 20-mL acid cleaned plastic bottle that was used for field analysis of (dissolved) Iron (2).
- An acid-cleaned 60-mL HDPE bottle containing 1:1 nitric acid as a preservative.

5.7.2.3 Low-flow samples

For the low-flow samples, whole-water samples were collected in

- 40-mL certified VOA vials containing acid.
- A 20-mL acid cleaned plastic bottle that was used for field analysis of (total) Iron (2).
- A60-mL acid-cleaned plastic bottle that contained the nitric acid preservative and was used for analyses of total metals.
- A 60-mL acid-cleaned plastic bottle that contained no preservative and was used for the analyses of sulfate and chloride.

An in-line filter *filtered* the low-flow samples (as described below). These samples were collected in

- A 20-mL acid cleaned plastic bottle that was used for field analysis of (dissolved) Iron (2).
- A 60-mL acid-cleaned plastic bottle that contained the nitric acid preservative and was used for analyses of total metals.

5.7.2.4 Filtration of the metals samples

The low-flow samples that were to be analyzed for dissolved metals were filtered using an additional length of tubing containing an in-line Teflon (PTFE) (0.45-µm) membrane filter. For the Snap Sampler samples that were filtered in the field, an aliquot was from the Snap bottle was drawn off in a 100-mL plastic syringe and then pushed through a Teflon membrane (0.45-µm) filter into an acid-cleaned bottle containing preservative (as described previously). Samples collected with the RGC sampler are already pre-filtered by the RGC membrane so did not need to be filtered. However, these samples are described as “unfiltered” in Table 5-4 because they were not filtered in the field.

5.7.2.5 Sampling personnel

Louise Parker, Nathan Mulherin, and Tommie Hall (ERDC-CRREL) conducted all the sampling at this site.

5.7.3 Sample Analyses

5.7.3.1 Field Analyses

Field analyses for Iron (2) were conducted using a Hach Colorimeter II test kit following the manufacturer’s guidelines.

5.7.3.2 Laboratory Analyses

To obtain a better understanding of the mechanism for each of these sampling methods, and the role of colloidal particulate matter in the transport of metals, both whole water and filtered water samples were analyzed for metals (from the Snap Sampler samples and the low-flow samples. The RGC samples were already pre-filtered by the RGC membrane so only analyses for filtered metals will be conducted for those samples.) All samples were analyzed within their specific holding times.

Table 5-6. Analytical methods for sample analysis.

Matrix	Analyte	Method	Container	Preservative[1]	Holding Time
Groundwater					
	VOCs	EPA Method 8260B	40-mL VOA vial		
	Metals	Prep.: EPA # 200.8 Analysis: SW846 #6020A	60-mL HDPE bottle	1:1 HNO_3	6 months
	Mercury	EPA SW846 Method 7470A, rev. 1	Same bottle as above	Same as above	28 days
	Anions	EPA Method 300.0	60-mL HDPE bottle	None Kept @ 4ºC	28 days
	Field Iron (2)	Hach II Colorimetric test kit	20-mL HDPE bottle	None	None

Table 5-6 summarizes the analytical methods used for the analyses of the various analytes.

Laboratory analyses were conducted by Curtis and Tompkins LTD (Berkeley, CA), which is an EPA-certified contract laboratory using standard EPA Methods. Specifically, VOCs were analyzed by EPA Method 8260B GC/MS (USEPA 1996). Metals were prepared for analyses using EPA Method 200.8 for trace elements in water and wastes by inductively coupled plasma/mass spectroscopy (ICP/MS) (USEPA 1994a) and analyses were by EPA SW846 Method 6020A for inductively coupled plasma-mass spectrometry (USEPA 2007). Mercury was analyzed using EPA SW846 method 7470A for liquid waste using a cold-vapor technique, revision 1 (USEPA 1994b). The anions were analyzed using EPA Method 300.0, revision 2.1 (USEPA 1993).

5.7.4 Data Handling

To eliminate problems with large amounts of data below the detection limit, only analytes where at least six of the wells had concentrations above the detection limit were used in the data analyses. In the few instances where analyte concentrations were below the reporting limit, the reporting limit was used in the statistical analyses.

5.7.5 Data Analyses

The data were analyzed on an analyte-by-analyte basis. The filtered and unfiltered data sets were treated separately.

5.7.5.1 Analyses of Data Quality Indicators

For the field duplicates, the relative percent difference (RPD) was calculated to determine the agreement between the duplicate samples. The RPD was calculated (for each well and analyte) according to the following formula:

$$RPD = [\ [\ |Conc._{\text{Sampler A}} - Conc._{\text{Sampler B}}|\ ] / [\text{Mean Conc.}_{\text{Sampler A \& B}}]\ ] \times 100$$

The number of wells where the RPD was 25% or less for analytes concentrations at or three times the reporting limit was then determined. The percent agreement between the two sampling methods was determined from the total number of wells.

5.7.5.2 Data Analyses Comparing the Sampling Methods

For the dissolved metals, analyte concentrations in the filtered Snap Sampler samples, filtered low-flow samples, and the RGC samplers were compared. For the total metals, and anions, analyte concentrations in the unfiltered Snap Sampler samples and the unfiltered low-flow samples were also compared. For the VOCs, analyte concentrations in the unfiltered Snap Sampler samples, unfiltered low-flow samples, and the RGC samplers were compared.

Standard statistical analyses were used to determine if there were significant differences between the sampling methods. In all cases, the data for each analyte were analyzed separately. The data sets were first analyzed to determine if the data were normally distributed and if the variances were homogenous. Whenever possible, conventional parametric analyses were used. Specifically, for normally distributed data, a Repeated Measures Analysis of Variance (RM-ANOVA) test was used to compare the three sampling methods and a paired-*t*-test was used when only two methods were being compared. (When a RM-ANOVA determined that there was a significant difference among the three sampling methods, the Holm-Sidak method was then used to determine which treatments were significantly different from each other.) If the data were not normally distributed or the variances were not homogeneous, the data were ln transformed and then retested using the same procedures as described previously. In instances where the transformed data still did not meet the requirements for normality and homogeneity of the variances, then a non-parametric test was used. A Friedman RM-ANOVA on Ranks test was used to compare the three treatments (followed by a Tukey test to determine which sampling methods differed from each other) and a Wilcoxon Signed Rank test was used when only two methods needed to be compared.

5.8 SAMPLING RESULTS

5.8.1 VOCS

Relatively low levels of only a few VOCs were found in the samples collected at this site.

5.8.1.1 Findings from the Analyses of the Field Duplicate Data

Tables 5-7, 5-8, and 5-9 present the field-duplicate data (for those analytes where concentrations were above the reporting limit) for low-flow sampling, the Snap Sampler, and the RGC sampler, respectively. Generally, agreement was quite good considering that many of the analyte concentrations were near the reporting limit. Our guideline for reproducibility was fairly stringent, with a Relative Percent Difference of 25% for analyte concentrations, providing that analyte concentrations were three times the reporting limit or greater. As an example, there is a 25% RDP between two replicate samples with concentrations of 78 and 100 ppb.

For the low-flow samples, only one analyte, TCE, had concentrations that were above the reporting limit, and the RPD was less than 5%. For the other analytes (where concentrations were less than three times the reporting limit), the RPD was less than 10%.

Table 5-7. Results for the field duplicate low-flow samples.

			Concentration (µg/L)		
Analyte	Reporting Limit	Well no.	Low-flow	LF Duplicate	RPD
Acetone	10	225	ND	ND	0
Carbon Disulfide	0.5	225	ND	ND	0
Carbon Tetrachloride	0.5	225	1.2	1.1	8.7
MTBE	0.5	225	ND	ND	0
Trichloroethene	0.5	225	2.7	2.8	3.6

Analytes in shaded boxes were near the reporting limit and were not considered in final summary.

Table 5-8. Results for the field duplicate Snap Sampler samples.

			Concentration (µg/L)		
Analyte	Well #	Reporting Limit	Snap Sampler	SS Duplicate	RPD
1,1-Dichloroethane	072	0.5	2.4	2.2	8.7
1,1-Dichloroethene	072	0.5	4	3.4	16
1,2-Dichloroethane	072	0.5	2.9	3.1	6.7
Acetone	072	10	ND	ND	0
	1065		ND	ND	0
Carbon Disulfide	072	0.5	5.1	2.9	55
	1065		ND	ND	0
cis-1,2-Dichloroethene	072	0.5	1.6	1.7	6.1
	1065		1.2	1.2	0.0
m,p-Xylenes	072	0.5	0.7	0.6	15
MTBE	072	0.5	0.5	41	195
	1065		2.6	2.9	11
o-Xylene	072	0.5	ND	ND	0
Tetrachloroethene	1065	0.5	1.4	1.4	0.0
Toluene	072	0.5	0.5	3	143
Trichloroethene	072	0.5	3.3	2.6	24
Vinyl Chloride	072	0.5	3	2.8	6.9

Analytes in shaded boxes were near the reporting limit.
For analytes in bold font, we replaced the RL as the value for ND.

Table 5-9. Results for the field duplicate RGC samples.

			Concentration (µg/L)		
Analyte	Reporting Limit	Well #	RGC	RGC Duplicate	RPD
Acetone	10	225	30	36	18
Carbon Disulfide	0.5	225	0.5	0.7	33
		437	ND	ND	0
Carbon Tetrachloride	0.5	225	1.1	1	9.5
		437	1.1	1.1	0.0
cis-1,2-Dichloroethene	0.5	437	ND	ND	0
MTBE	0.5	225	16	18	12
		437	10	10	0.0
Trichloroethene	0.5	225	2.8	2	33
		437	1.4	1.4	0.0

Analytes in shaded boxes were near the reporting limit.

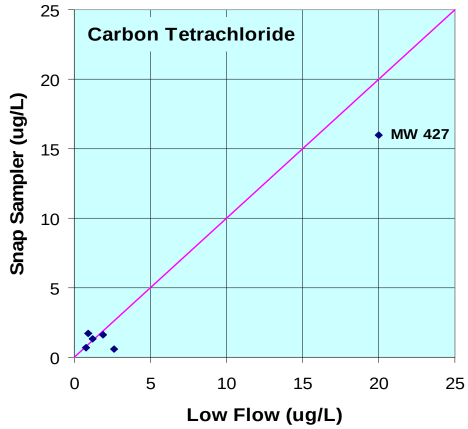
For analytes in bold font, we replaced the RL as the value for ND.

For the Snap Sampler and RGC samples, there was more variability in the data. This is to be expected given the individual nature of these samples vs. the low-flow samples that are poured into the VOA vials almost simultaneously. The Snap and RGC samplers provided reproducible results most of the time. For the Snap Sampler samples, the RPD was within our guideline (with a RPD of 25% or less) for all but one of the comparisons when both analyte concentrations exceeded the required three times the reporting limit standard. There were two other instances where there was a large RPD, but in those cases one of the analyte concentrations was at the reporting limit; this occurred in the samples collected from well 72 for MTBE and Toluene.

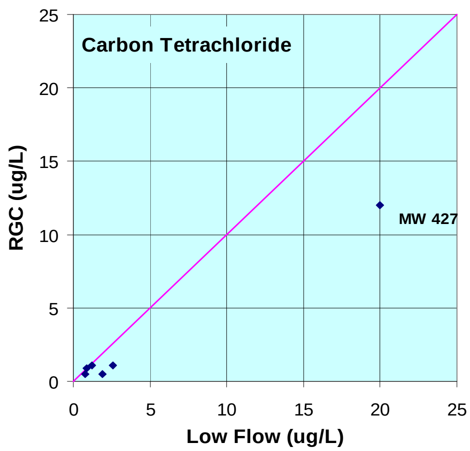
For the RGC samples, the RPD ranged from 0 to 33% for those concentrations that were above the reporting limit, and three of the four comparisons were within the 25% guideline for the RPD.

5.8.1.2 Comparison of the Three Sampling Methods

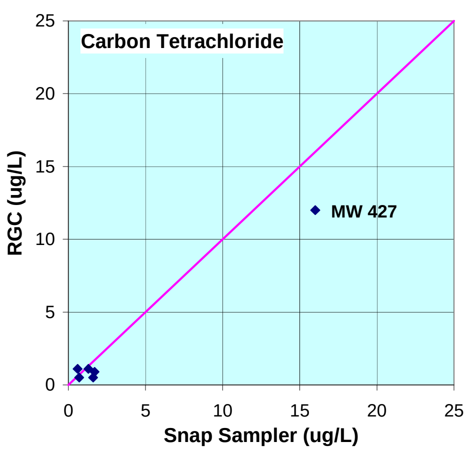
Because relatively low levels of VOCs were found in these samples, this limited the number of analytes where statistical analyses could be conducted. The analytes that were found at high enough concentrations to allow statistical analyses were carbon tetrachloride, *cis*,1,2-DCE (cDCE), methyl tert-butyl ether (MTBE), and trichloro-ethylene (TCE). Figures 5-6 through 5-9 show the comparisons of the Snap Sampler vs. low-flow sampling, the RGC sampler vs. low-flow sampling, and the RGC sampler vs. the Snap Sampler for each of these analytes, respectively. These figures also contain a line with a slope of 1.0 and a 0 intercept. This allows the reader to easily observe whether there was a 1:1 correlation.



a. Comparison between the Snap Sampler and low-flow sampling.

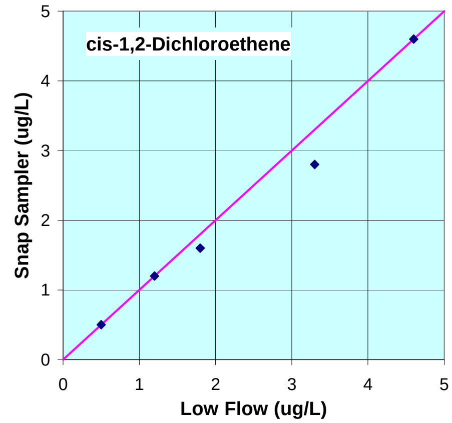


b. Comparison between the RGC sampler and low-flow sampling.

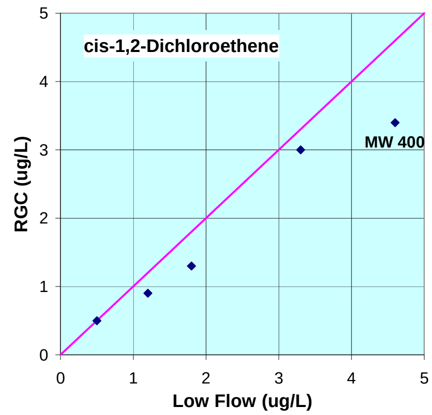


c. Comparison between the RGC sampler and the Snap Sampler.

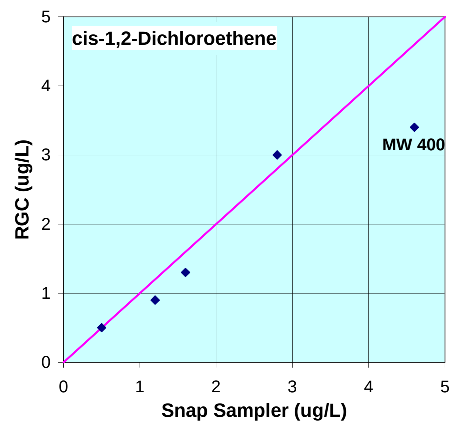
Figure 5-6. Comparison of the sampling methods for carbon tetrachloride.



a. Comparison between the Snap Sampler and low-flow sampling.

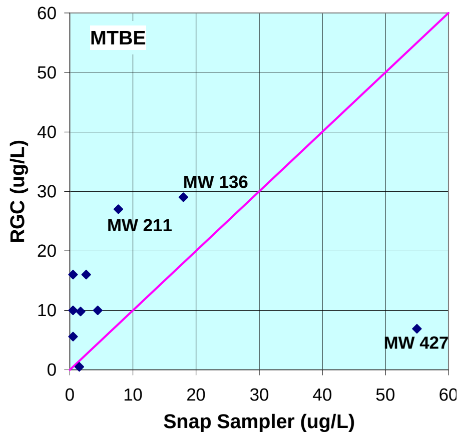


b. Comparison between the RGC sampler and low-flow sampling.

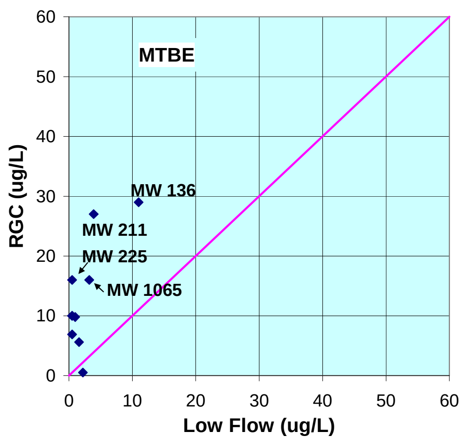


c. Comparison between the RGC sampler and the Snap Sampler.

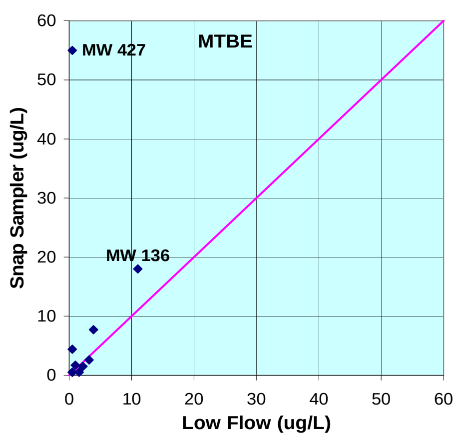
Figure 5-7. Comparison of the sampling methods for *cis*-1,2-dichloroethylene.



a. Comparison between the Snap Sampler and low-flow sampling.

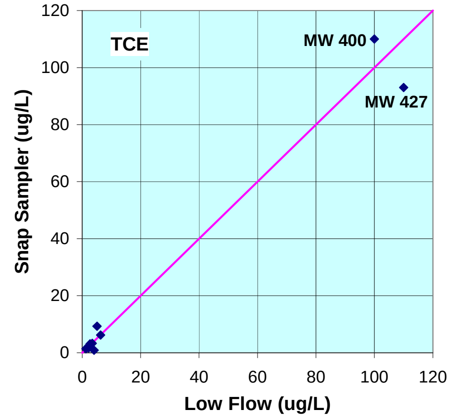


b. Comparison between the RGC sampler and low-flow sampling.

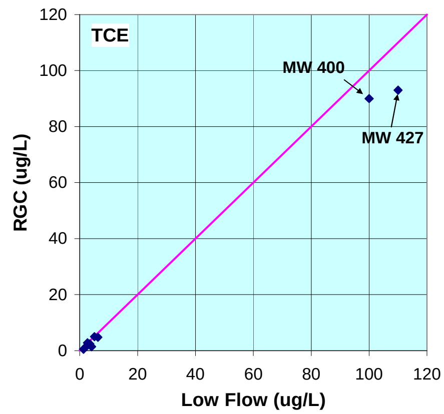


c. Comparison between the RGC sampler and the Snap Sampler.

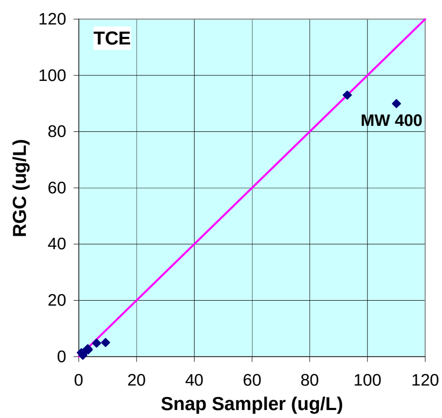
Figure 5-8. Comparison of the sampling methods for MTBE.



a. Comparison between the Snap Sampler and low-flow sampling.



b. Comparison between the RGC sampler and low-flow sampling.



c. Comparison between the RGC sampler and the Snap Sampler.

Figure 5-9. Comparison of the sampling methods for Trichloroethylene.

Table C1 provides all the data for each well, sampling method, and analyte.

Statistical analyses of the data for carbon tetrachloride and cDCE revealed that there were no statistically significant differences between the three sampling methods (Table C2). This can be seen by examining Figures 5-6a, 5-6b, 5-6c, 5-7a, 5-7b, and 5-7c. There also were no statistically significant differences between the Snap Sampler and the low-flow sampling data for MTBE and TCE (Table C2).

The linear model was a good fit for the comparisons between the low-flow and Snap Sampler data for carbon tetrachloride, *cis*-DCE, and TCE but not MTBE (Table C3, Fig. 5-6a, 5-7a, 5-8a, and 5-9a). The linear model became a good fit for the MTBE data once one well (427) (a possible outlier) was eliminated. The RPD for the field duplicate MTBE data for the Snap Sampler was highly variable in one of the two instances; again, this variability was most likely because of the relatively low concentrations of this analyte.

For MTBE, the linear model fit the data that compared the RGC samples with the low-flow samples but only did so for the comparison between the RGC samplers and the Snap Samplers after the data from well 427 (a possible outlier) was eliminated (Table C3). Statistical analyses revealed that MTBE concentrations were significantly higher in the RGC samples than in either the low-flow samples or the Snap samples (Table C2). This can be seen by examining Figures 5-8b and 5-8c, respectively.

It is not clear why concentrations of MTBE would be higher in the RGC samples than in the Snap Sampler or low-flow samples. MTBE has the lowest Octanol/Water Partition (Kow) value of these four analytes and thus would be the least likely to be associated with organic particulates in the well water. (If a contaminant was particle-borne, one would expect that concentrations would be lowest in the RGC samplers as these samples are naturally filtered by the sampler membrane.) This analyte is highly soluble in water; more so than the other analytes. However, it is not clear how this difference would result in much higher concentrations of this analyte in the RGC samplers. This difference may be attributable to the temporal nature of this (diffusion) sampler. (Typically, concentrations in diffusion samplers represent a time-weighted average over the last several sampling days. It may be that the concentrations of this analyte in the wells were higher on the previous days than on the day the low-flow and Snap Sampler samples were collected.) However, it seems unlikely that this would have occurred in all the wells.

For TCE, the linear model fit comparisons between the low-flow and RGC data, and between the RGC and Snap Sampler data. In both cases the slope of the line was less slightly less than 1.0 (Table C3). This indicates that the concentrations of TCE were lower in the RGC samples than the two other sampling methods. Statistical analyses revealed that this difference was statistically significant when the RGC samples were compared with the low-flow samples, but not when the RGC samples were compared with the Snap Sampler samples (Table C2).

Although not included in the statistical analyses (because many of the data were either at or near the reporting limit), another trend we observed was that very low concentrations (i.e., just above the reporting limit) of acetone were detected in the RGC samples but not in the Snap Sampler samples or the low-flow samples (Table C1). The reason for this difference may be the same as

that for MTBE, or it may be because of differences in the handling of this sampler. Once we arrived in the field, we had to place the RGC samplers in a sparging chamber (to deoxygenate the DI water in the sampler). The DI water we used for this process was purchased from multiple sources and some of the bottles of DI water could have been the source of this contamination. Other sources of this analyte could have been components of the sparging equipment or possibly the field-laboratory environment itself as acetone is a common laboratory contaminant. Unfortunately, we had not anticipated that we would need to collect additional equipment blank samples and thus did not have the flexibility to conduct additional sampling that would have allowed us to test the various sources of DI water. The equipment blanks for a newly constructed RGC sampler did not contain acetone, and one co-author (T. Imbrigiotta) has not found it to be a contaminant in his studies. This tends to implicate the bottled distilled water that was purchased on site.

Although the RGC samplers have been used successfully in the past for sampling for MTBE (ITRC 2006), it is interesting that both MTBE and acetone concentrations were higher in the RGC samplers than in the other samplers. Both of these analytes are highly soluble in water. Vroblesky and Campbell (2001) found that the PDB sampler (with a PE membrane) should not be used for several highly soluble analytes, specifically acetone, MTBE, and Methyl Isobutyl Ketone.

5.8.1.3 Well-by-well comparisons

There were two wells where there were apparently substantial differences between analyte concentrations for the three sampling methods. In monitoring well 427, there were differences between analyte concentrations for three analytes: carbon tetrachloride, MTBE, and TCE. For well 400, there were differences between the cDCE and TCE concentrations. These relationships are summarized in Table 5-10. There does not appear to be any consistent bias that can be associated with the sampling methods and the well. There also were large differences in the MTBE concentrations with the three sampling methods for wells 136, 211, 225, and 1065.

Table 5-10. Summary of the recovery of analytes between sampling methods in wells 427 and 400.

Well #	Analyte	Relationship
427	Carbon Tetrachloride	LF > RGC > SS
	MTBE	SS > LF = RGC
	TCE	LF > SS = RGC
400	cDCE	RGC > SS = LF
	TCE	SS > LF > RGC

5.8.1.4 Conclusions for the VOC analytes

The four VOCs found in these wells (carbon tetrachloride, cDCE, MTBE, and TCE) were generally at very low concentrations. This makes statistical analyses of these data more problematic. However, the field duplicate data were generally within our guideline for precision (i.e., RPD ≤ 25%).

The Snap Sampler recovered concentrations of all four analytes equivalent to those recovered using low-flow sampling.

The RGC sampler recovered equivalent concentrations of carbon tetrachloride and cDCE. However, concentrations of MTBE and acetone were higher in the RGC samples than the low-flow or Snap Sampler samples. It is not clear why this would be the case. Both analytes are highly soluble; acetone may have been a contaminant in the bottled distilled water in which these samplers were placed but that wouldn't explain the high elevated levels of MTBE in these samplers. In contrast, concentrations of TCE were significantly lower in the RGC samplers than those collected using low-flow sampling (but not the Snap Sampler).

5.8.2 Dissolved Inorganic Analytes

The analyses for dissolved metals included aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), potassium (K), sodium (Na), vanadium (V), and zinc (Zn). The dissolved inorganic analytes found at this site included one metalloid (As), two alkali metals (K and Na), three alkaline earth metals (Ba, Ca, and Mg), and three transition metals (Cr, Ni, and V).

5.8.2.1 <u>Findings from the Analyses of the Field Duplicate Data</u>

Tables 5-11, 5-12, and 5-13 present the field-duplicate data for the filtered metals samples collected using low-flow sampling, the Snap Sampler, and the RGC samplers, respectively. Generally, agreement was within our guideline (25% RPD) for most of the analytes for the three sampling methods; the exceptions were when the concentrations were near the detection limit.

For Ba, Ca, Cr, Mg, Ni, K, Na, and V, the analyte concentrations were well above the reporting limit (at least five times the RL). For these analytes, the agreement between replicate field samples was excellent. Specifically, the RPDs were less than 10% for most of the samples and were less 25% in all cases except one (where the RPD was only slightly greater than the guideline).

The analytes where the concentrations were close to reporting limit were As, Cu, Mn, and Zn. For As and Mn, the RPDs were within the guidelines for all three sampling methods. For Zn, the RPDs for the field duplicate samples were within the guideline for low-flow sampling and the Snap Samplers but exceeded the guideline in two instances for the RGC samplers. For Cu, the RPDs for low-flow sampling were within the guideline but exceeded the guideline in one instance for the Snap Sampler and in two instances for the RGC sampler. (For the Snap Sampler, the concentrations in the two duplicate samples were 4.1 µg/L and non-detect [less than 1.0 µg/L] yielding a large RPD [125%]. For the RGC sampler, the concentrations for the duplicate samples ranged from below the reporting limit [1.0 µg/L] to 1.9 µg/L and the RPDs ranged from 8 to 46%). However, one would expect poorer precision for these analytes because the concentrations were either at or near the reporting limit.

Table 5-11. Results for field duplicate samples for low-flow sampling

			Concentration (µg/L)		
Analyte	Reporting Limit	Well #	Low-Flow	LF Duplicate	RPD
Arsenic	1	225	3	3.7	21
		427	1.6	1.8	12
Barium	1	225	49	48	2.1
		427	170	170	0.0
Calcium	50	225	14000	14000	0.0
		427	58000	59000	1.7
Chromium	1	225	15	15	0.0
		427	7	7.1	1.4
Copper	1	225	**1.0**	1.2	18
		427	**1.0**	**1.0**	0
Magnesium	50	225	9900	9800	1.0
		427	40000	41000	2.5
Manganese	1	225	**1.0**	1.1	9.5
		427	1.2	1.4	15
Nickel	1	225	8.2	8.1	1.2
		427	5.7	5.8	1.7
Potassium	50	225	1200	1300	8.0
		427	2100	2200	4.7
Sodium	60	225	14000	14000	0.0
		427	27000	28000	3.6
Vanadium	1	225	30	30	0.0
		427	19	19	0.0
Zinc	5	225	ND	ND	0
		427	ND	ND	0

Analytes in shaded boxes were at or near the reporting limit.
For analytes in bold font, we replaced the RL as the value for ND.

Table 5-12. Results for field duplicate samples for the Snap Sampler.

			Concentration (µg/L)		
Analyte	Reporting Limit	Well #	Snap Sampler	SS Duplicate	RPD
Arsenic	1	1065	2.7	2.6	3.8
Barium	1	437	45	46	2.2
		1065	50	55	9.5
Calcium	50	437	13000	13000	0.0
		1065	18000	19000	5.4
Chromium	1	437	13	14	7.4
		1065	11	11	0.0
Copper	1	437	1.1	**1.0**	9.5
		1065	4.1	**1.0**	122
Iron Field Fe(2)	10	437	ND	ND	0
Magnesium	50	437	9400	9400	0.0
		1065	12000	13000	8.0
Manganese	1	1065	3.2	2.6	21
Nickel	1	1065	51	54	5.7
Potassium	50	437	1100	1100	0.0
		1065	1300	1400	7.4
Sodium	60	437	13000	13000	0.0
		1065	23000	24000	4.3
Vanadium	1	437	30	30	0.0
		1065	20	20	0.0
Zinc	5	437	6.4	5	25
		1065	ND	ND	0

Analytes in shaded boxes were at or near the reporting limit.
For analytes in bold font, we replaced the RL as the value for ND.

Table 5-13. Results for field duplicate samples for the RGC sampler.

			Concentration (µg/L)		
Analyte	Reporting Limit	Well #	RGC	RGC Duplicate	RPD
Arsenic	1	225	3.2	3.1	3.2
		400	2.7	2.9	7.1
		1065	3	2.5	18
Barium	1	225	54	55	1.8
		400	95	92	3.2
		437	45	47	4.3
		1065	54	54	0.0
Calcium	50	225	14000	14000	0.0
		400	31000	30000	3.3
		437	13000	13000	0.0
		1065	19000	19000	0.0
Chromium	1	225	14	16	13
		400	9.8	9.9	1.0
		437	13	13	0.0
		1065	10	10	0.0
Copper	1	225	**1**	1.4	33
		400	1.9	1.5	23
		437	1.6	**1**	46
		1065	1.2	1.3	8.0
Iron Field Fe(2)	10	072	3300	2920	12
		225	**10**	**10**	0
		1065	**10**	**10**	0
Magnesium	50	225	9900	9700	2.0
		400	22000	22000	0.0
		437	9700	10000	3.0
		1065	13000	13000	0.0
Manganese	1	225	**1**	**1**	0
		1065	3.8	3.4	11.
Nickel	1	225	9.3	8.3	11.
		400	1	**1**	0.0
		1065	69	54	24
Potassium	50	225	1900	2000	5.1
		400	1800	1700	5.7
		437	1200	1200	0.0
		1065	1600	2100	27
Sodium	60	225	14000	14000	0.0
		400	23000	24000	4.3
		437	13000	14000	7.4
		1065	23000	24000	4.3
Vanadium	1	225	30	29	3.4
		400	26	25	3.9
		437	30	30	0.0
		1065	20	20	0.0
Zinc	5	225	**5**	6.1	20
		400	17	11	43
		437	7.3	**5**	37
		1065	5.9	**5**	16

Analytes in shaded boxes were at or near the reporting limit.
For analytes in bold font, we replaced the RL as the value for ND.

5.8.2.2 Comparison of the Three Sampling Methods

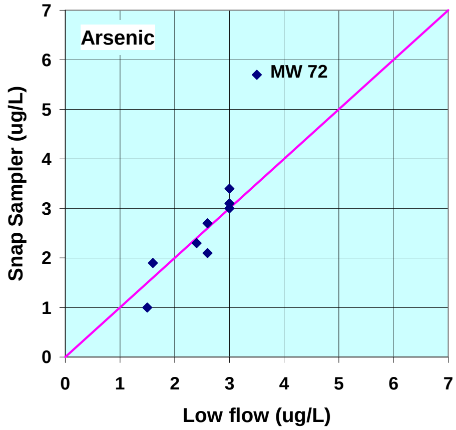
While Al, Sb, Cd, Co, Cu, Fe, Fe (2), Mo, and Zn were detected in some wells, analyte concentrations were at or near the detection limit in most of them. The analytes that were found at high enough concentrations to allow statistical analyses were As, Ba, Ca, Cr, Mg, Ni, K, Na, and V. Figures 5-10 through 5-18 show the pair-wise comparisons for the three sampling methods for each of these analytes. The raw data for each analyte, well, and sampling method can be found in Table D1.

Examination of these figures reveals that there was generally exceptionally good agreement between the three sampling methods. The poorest agreement between the three sampling methods appears to be for K, where analyte concentrations for the RGC samplers were slightly higher than for either low-flow sampling or the Snap Samplers (Fig. 5-16a and c). The linear model was significant for all the comparisons, and generally the slope was not significantly different from 1.0 for the comparisons between the Snap Sampler and low-flow samples and between the RGC and the Snap Sampler samples (Table D3). In contrast, the slope was significantly different from 1.0 for several analytes when the RGC and Snap Sampler samples were compared (Table D2).

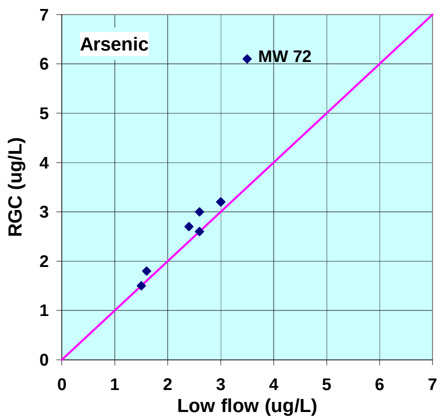
Statistical analyses of the data revealed that there were no statistically significant differences between the three sampling methods for As, Ca, Cr, Ni, and V (Table D3). There were no statistically significant differences between the low-flow and Snap Sampler samples for any of the other analytes as well (Table D3).

However, for the RGC samplers concentrations of four analytes (Ba, Mg, K, and Na) were significantly higher than the low-flow samples. Examination of the figures that show these comparisons (Fig. 5-11b, 5-14b, 5-16b, and 5-17b) reveals that these differences were generally very small, especially for Ba, Mg, and Na. A linear-least-fit model of these data (Table D2) showed that the slope of the line for the Ba data was not significantly different from 1.0, and the slope for the lines for the Mg and Na data were only slightly greater than 1.0 (i.e., 1.05 and 1.08, respectively). The difference between the two sampling methods was most pronounced for K, where the slope was 1.15.

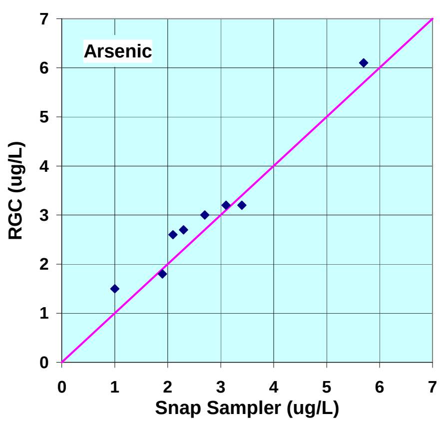
Concentrations of K were also significantly higher in the RGC samplers than the Snap Sampler. These findings are somewhat perplexing given that K, Mg, and Na are the most soluble analytes. Also, given that the membrane used to filter the low-flow and Snap Sampler samples had a much larger pore size (0.45 µm) than the RGC sampler membrane (0.0018 µm), we would have expected that the RGC samples might have had slightly lower concentrations than the low-flow and Snap Sampler samples.



a. Comparison between the Snap Sampler and low-flow sampling.

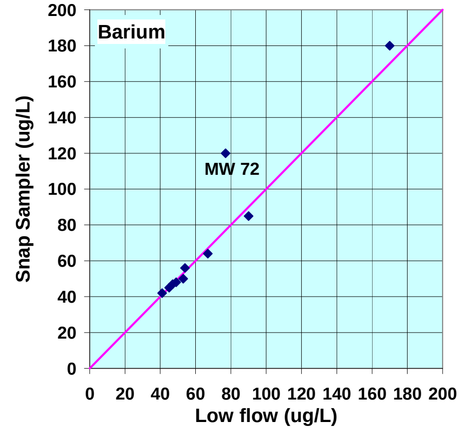


b. Comparison between the RGC sampler and low-flow sampling.

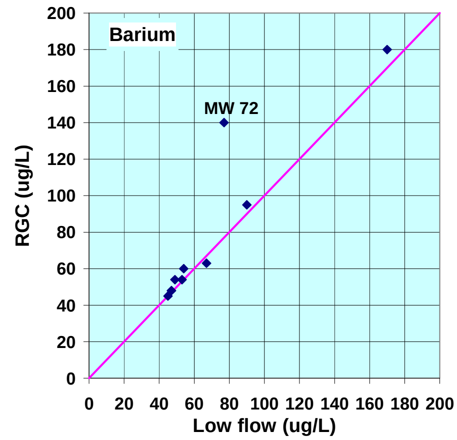


c. Comparison between the RGC and Snap samplers.

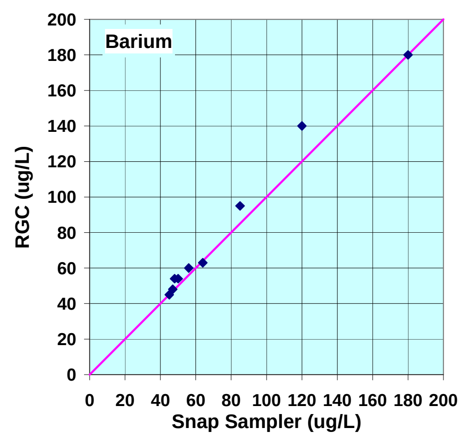
Figure 5-10. Comparison of sampling methods for dissolved As.



a. Comparison between the Snap Sampler and low-flow sampling.

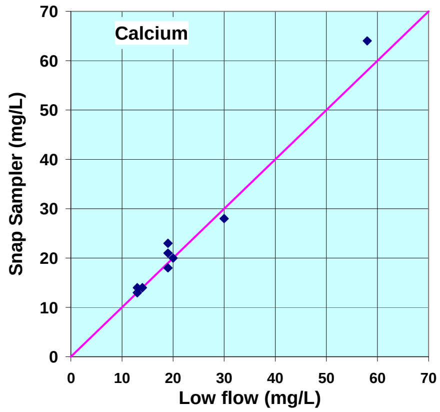


b. Comparison between the RGC sampler and low-flow sampling.

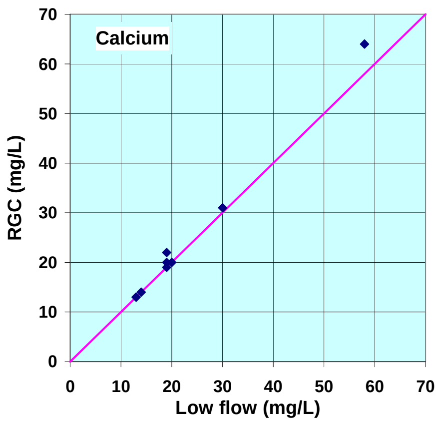


c. Comparison between the RGC and Snap samplers.

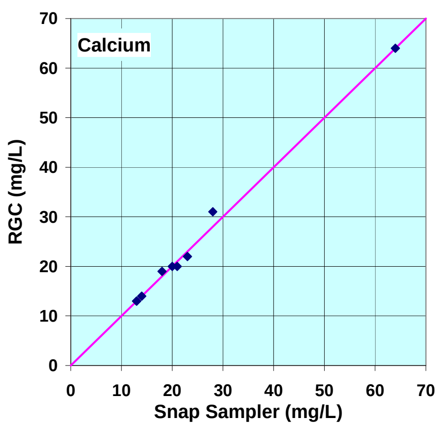
Figure 5-11. Comparison of sampling methods for dissolved Ba.



a. Comparison between the Snap Sampler and low-flow sampling.

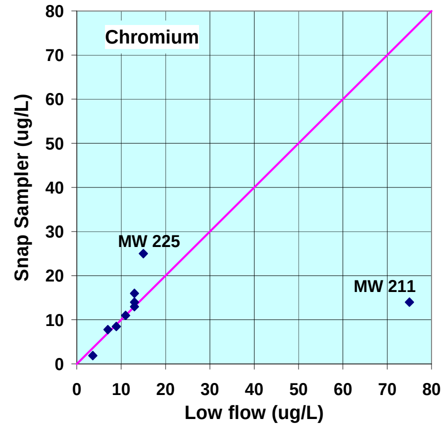


b. Comparison between the RGC sampler and low-flow sampling.

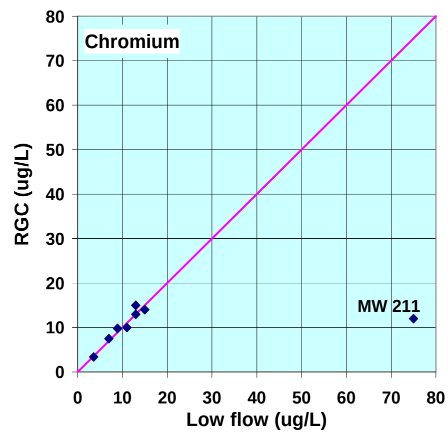


c. Comparison between the RGC and Snap samplers.

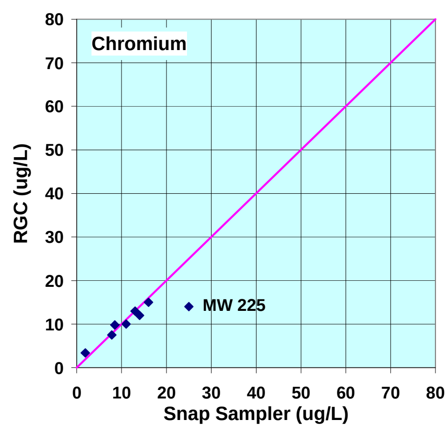
Figure 5-12. Comparison of sampling methods for dissolved Ca.



a. Comparison between the Snap Sampler and low-flow sampling.

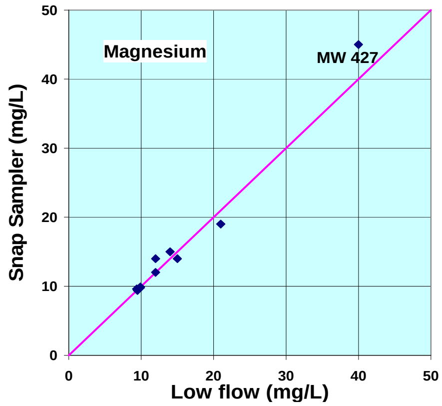


b. Comparison between the RGC sampler and low-flow sampling.

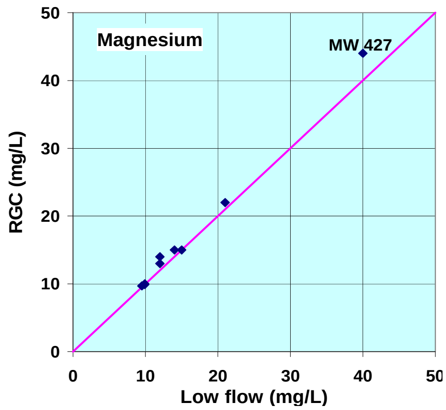


c. Comparison between the RGC and Snap samplers.

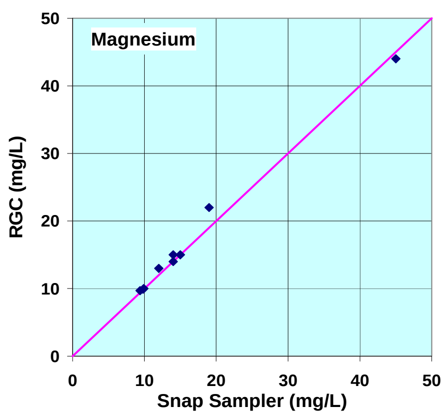
Figure 5-13. Comparison of sampling methods for dissolved Cr.



a. Comparison between the Snap Sampler and low-flow sampling.

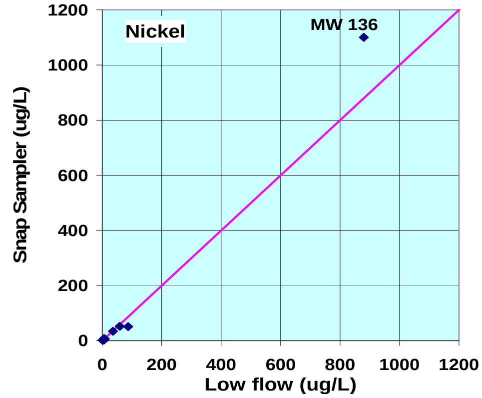


b. Comparison between the RGC sampler and low-flow sampling.

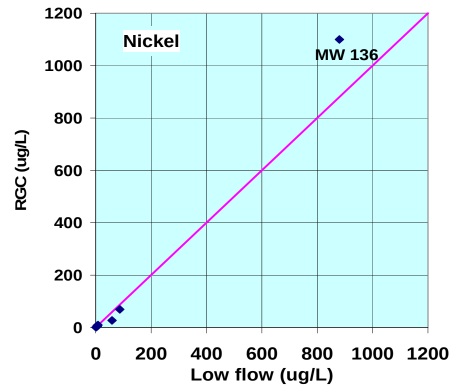


c. Comparison between the RGC and Snap samplers.

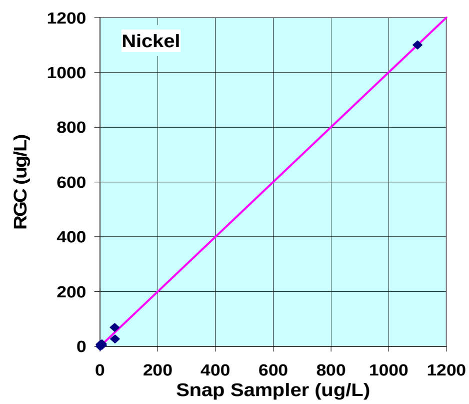
Figure 5-14. Comparison of sampling methods for dissolved Mg.



a. Comparison between the Snap Sampler and low-flow sampling.

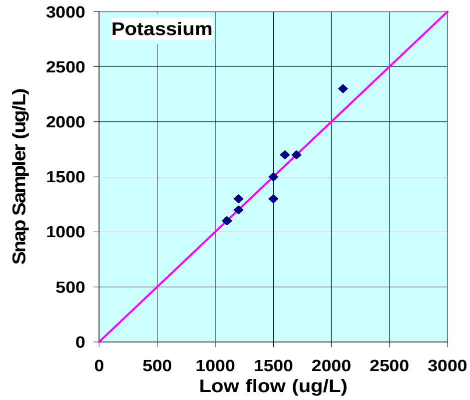


b. Comparison between the RGC sampler and low-flow sampling.

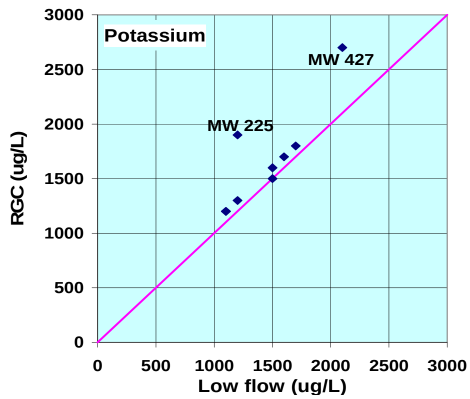


c. Comparison between the RGC and Snap samplers.

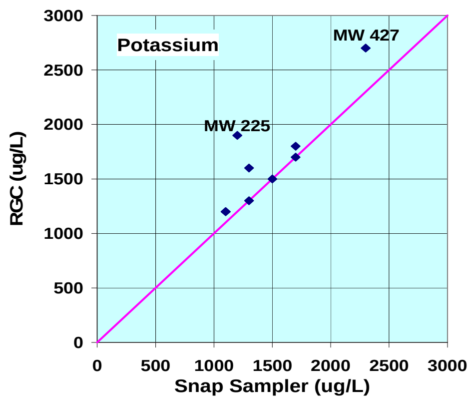
Figure 5-15. Comparison of sampling methods for dissolved Ni.



a. Comparison between the Snap Sampler and low-flow sampling.

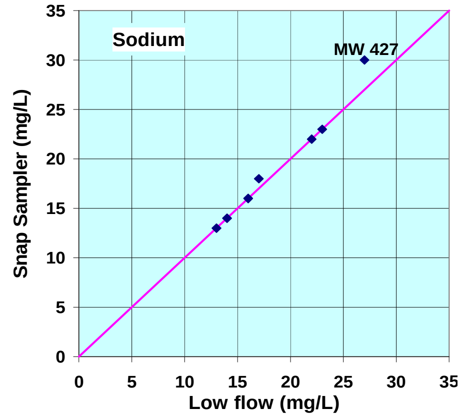


b. Comparison between the RGC sampler and low-flow sampling.

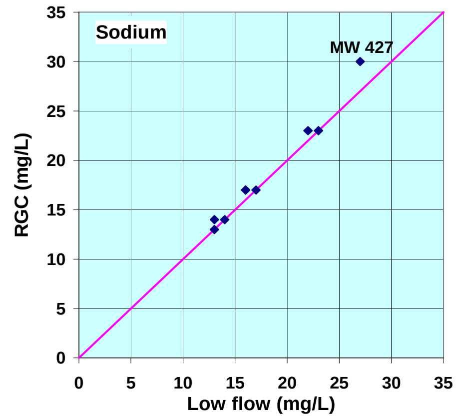


c. Comparison between the RGC and Snap samplers.

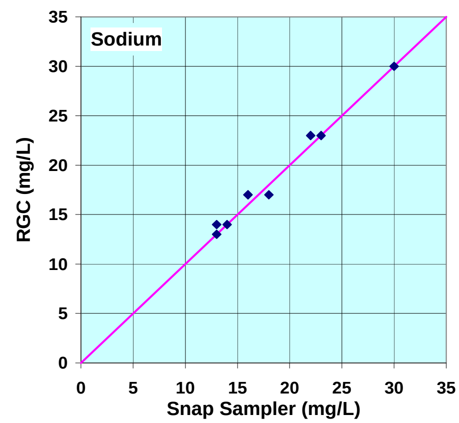
Figure 5-16. Comparison of sampling methods for dissolved K.



a. Comparison between the Snap Sampler and low-flow sampling.

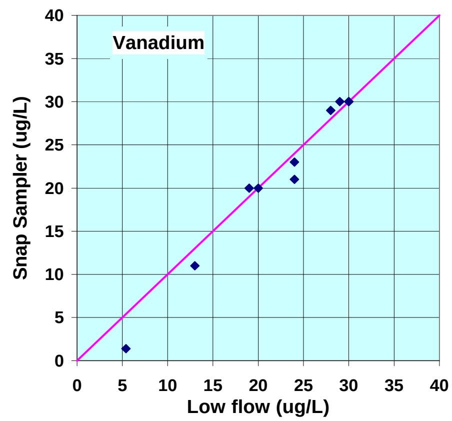


b. Comparison between the RGC sampler and low-flow sampling.

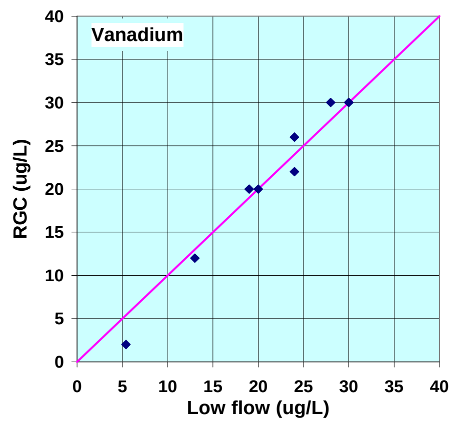


c. Comparison between the RGC and Snap samplers.

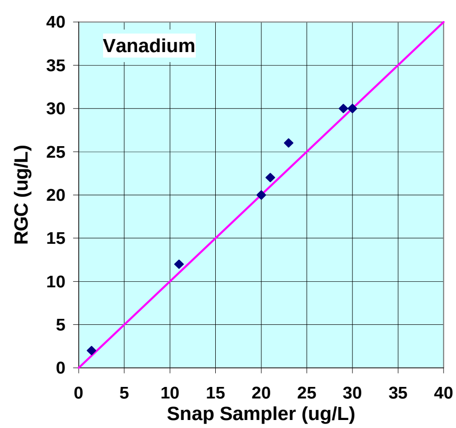
Figure 5-17. Comparison of sampling methods for dissolved Na.



a. Comparison between the Snap Sampler and low-flow sampling.



b. Comparison between the RGC sampler and low-flow sampling.



c. Comparison between the RGC and Snap Samplers.

Figure 5-18. Comparison of sampling methods for dissolved Vanadium.

5.8.2.3 Analysis of the data on a well-by-well basis

For the dissolved inorganic analytes, there was generally an excellent agreement between the sampling methods, with only a few wells where there appears to be poor agreement. For the wells where there were differences, these differences are summarized in Table 5-16. Generally, the Snap Sampler concentrations tended to agree with those found in the RGC samplers. As we saw previously with the VOCs, well 427 showed the poorest agreement between the sampling methods.

Table 5-16. Relationships between analyte concentrations in wells where there was poor agreement between the sampling methods.

Well #	Analyte	Relationship
72	As	RGC = SS > LF
	Ba	RGC = SS > LF
	V	LF > SS = RGC
136	Ni	RGC = SS > LF
211	Cr	SS > RGC > LF
225	Cr	SS > LF = RGC
	K	RGC > SS = LF
427	Mg	RGC = SS > LF
	K	RGC > SS = LF
	Na	RGC > SS = LF

5.8.2.4 Conclusions for the Dissolved Inorganic Analytes

Given that there is generally excellent agreement between the three sampling methods, we conclude that any of these three sampling methods could be used for dissolved inorganics.

5.8.3 Total Inorganic Analytes

Total concentrations of the inorganic analytes were only measured for low-flow sampling and the Snap Sampler. This was because the RGC membrane prevents particles from entering the sampler. Total inorganic analytes that were found at measureable concentrations included: two non-metal anions, one metalloid, two alkali metals, three alkaline earth metals, and several transition metals.

5.8.3.1 Total Non-Metal Anions

The non-metal anions were chloride and sulfate.

5.8.3.1.1 Findings from the Field Duplicate Data for Total Non-Metal Anions

Table 5-17 gives the results from the analyses of the field duplicate samples and the RPD between the two replicate field samples for the two non-metal anions found at this site.

For chloride, agreement was excellent, with a RPD of 0%. The agreement was also quite good (i.e., were within our guideline of 25%) for sulfate. The only exception was well 72 where the analyte concentrations were near the reporting limit.

Table 5-17. Results for the field duplicate samples.

Analyte	Well #	Concentration (mg/L)			Well #	Concentration (mg/L)		
		LF	LF Duplicate	RPD		SS	SS Duplicate	RPD
Chloride	211	22	22	0	072	17	17	0
	225	13	13	0	211	22	22	0
	427	89	89	0	427	92	92	0
Sulfate	211	3.8	3.8	0	072	1.1	1.8	48
	225	1.5	1.5	0	211	3.9	3.8	2.6
	427	15	15	0	225	14	14	0.0

Analytes in shaded boxes were near the detection limit.

5.8.3.1.2 Comparison of the Two Sampling Methods for the Non-metal Anions

Figures 5-19 and 5-20 present the total chloride and total sulfate concentrations in the Snap Sampler vs. low-flow sampling, respectively. The raw data can be found in Table E1. For both analytes, there was excellent agreement between the two sampling methods. The linear model was a good fit for both sets of data, although the slope was slightly more than 1.0 (1.03) for the chloride data (Table E3). However, statistical analyses revealed that there was no significant difference between the two sampling methods (Table E2).

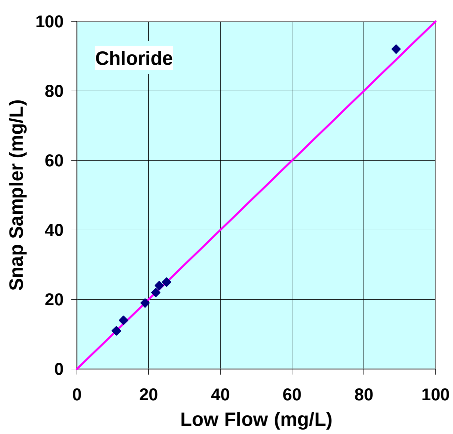


Figure 5-19. Comparison between the Snap Sampler and low-flow sampling for total chloride.

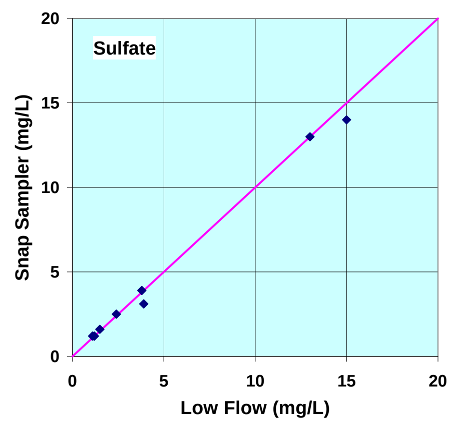


Figure 5-20. Comparison between the Snap Sampler and low-flow sampling for total sulfate.

5.8.3.2 Total Metals and Metalloids

The total metals and metalloids included the following analytes. The one metalloid was As, the two alkali metals were K and Na, and the three alkaline earth metals were Ba, Ca, and Mg. The transition metals included Co, Cr, Cu, Fe, Mn, Mo, Ni, V and Zn.

5.8.3.2.1 Findings for the field duplicate data

Table 5-18 gives the results from the analyses of the field duplicate samples and the RPD between the two values. Analysis of the duplicate data for both sampling methods revealed that Ca, Mg, K, and Na had RPDs that consistently met our guideline (25% RPD). The precision for As, Ba, and Ni was also generally within the guideline.

In contrast, the precision was very poor for Cr, Co, Cu, Fe, Mn, and Mo for both sampling methods. In addition, the precision for the Snap Sampler data was very poor for V. However, we would expect that the precision would be poorer for Co and Mo because the concentrations were near the reporting limit. Because of the large variability in the data for several of these analytes, the results from the statistical analyses for these analytes should be taken with caution when no significant difference is found.

Table 5-18. Findings for the field duplicate samples. Concentrations in µg/L unless marked with an asterisk.

Analyte	Reporting Limit	Well #	LF	LF Dupe	RPD	Well #	SS	SS Dupe	RPD
As	1	**211**	2.4	2.5	4.1	**72**	6.6	6.8	3.0
		225	3.3	3.4	3.0	**211**	2.8	2.2	24
		427	1.9	1.7	11	**427**	1.8	3.2	56
Ba	1	**211**	63	63	0.0	**72**	130	95	31
		225	53	52	1.9	**211**	66	61	7.9
		427	170	170	0.0	**427**	170	210	21
Ca*	0.050	**211**	19	20	5.1	**72**	24	20	18
		225	15	14	6.9	**211**	20	19	5.1
		427	58	60	3.4	**427**	60	62	3.3
Cr	1	**211**	59	69	16	**72**	3.4	11	106
		225	76	210	94	**211**	220	73	100
		427	73	15	132	**427**	91	2300	185
Co	1	**211**	1.9	1.9	0.0	**72**	4.3	1.3	107
		225	1.9	2.8	38	**211**	1.0	5.4	137
		427	1.0	1.0	0.0				

Analyte	Reporting Limit	Well #	LF	LF Dupe	RPD	Well #	SS	SS Dupe	RPD
Cu	1	**211**	3.6	3.8	5.4	**72**	1.0	2.1	71
		225	3.9	2.9	29	**211**	6.8	3.6	61
		427	4.5	1.1	121	**427**	2.6	18	149
Fe*	0.050	**211**	0.28	0.30	6.9	**72**	5.6	12	73
		225	0.32	0.82	88	**211**	0.85	0.30	96
		427	0.49	0.21	80	**427**	1.1	12	166
Mg*	0.050	**211**	14	14	0.0	**72**	15	13	14
		225	10	10	0.0	**211**	14	13	7.4
		427	41	41	0.0	**427**	42	43	2.4
Mn	1	**211**	23	23	0.0	**72**	230	220	4.4
		225	29	42	37	**211**	49	14	111
		427	4	2.4	50	**427**	4.8	52	166.
Mo	1	**211**	**1.0**	**1.0**	0.0	**72**	2.2	1.9	15
		225	1.2	3.6	100	**211**	2.5	**1.0**	86
		427	**1.0**	**1.0**	0.0	**427**	1.0	7.1	151
Ni	1	**211**	51	53	3.8				
		225	34	44	26	**211**	61	49	22
		427	8.9	7	24	**427**	9.5	72	154
K*	0.050	**211**	1.4	1.4	0.0	**72**	1.3	1.2	8.0
		225	1.3	1.3	0.0	**211**	1.4	1.4	0.0
		427	2.1	2.2	4.7	**427**	2.1	2.2	4.7
Na*	0.060	**211**	15	16	6.5	**72**	17	16	6.1
		225	15	14	6.9	**211**	15	15	0.0
		427	27	28	3.6	**427**	28	28	0.0
V	1	**211**	22	23	4.4	**72**	4.1	22	137
		225	33	33	0.0	**211**	24	21	13
		427	19	19	0.0	**427**	20	37	60
Zn	5	All at or near detection limit							

*Concentrations are in mg/L
Analytes in shaded boxes were at or near the reporting limit.
For analyte concentrations in red bold font, ND was replaced with the reporting limit.

Precision for the field duplicates appeared to be better in some wells than others and generally was better for low-flow sampling than for the Snap Sampler, although not always.

5.8.3.2.2 Comparison of Low-flow and Snap Sampler data for Total Metals

Table E4 gives the concentrations of each of the analytes for each well and sampling method. It appears that concentrations of As, Ba, Ca, Mg, K, Na, and V agreed well between the two sampling methods, as shown in Figures 5-21 through 5-27. Statistical analyses determined that there were no significant differences between the two sampling methods for these analytes (Tables E6 and E7). Analyses using a linear least-fit model showed that more 98% of the variance observed could be explained by a linear model (Table E3).

Agreement was not as good for Cr, Co, Cu, Fe, Mn, Mo, Ni, and Zn (Fig. 5-28 through 5-35). A linear-least-fit model of the data showed that the linear model was a poor fit for Cr, Cu, Fe, and especially Zn (Table E3). Statistical analyses of the data revealed that there were no significant differences between the two sampling methods for Cr, Co, Cu, Mo, Ni, and Zn (Tables E5 and E6). This is not unexpected given that analyte concentrations were near the reporting limit for Co, Cu, Mo, and Zn and there was substantial variability between the replicate samples for these analytes. There also was very poor agreement between the duplicate samples for Cr.

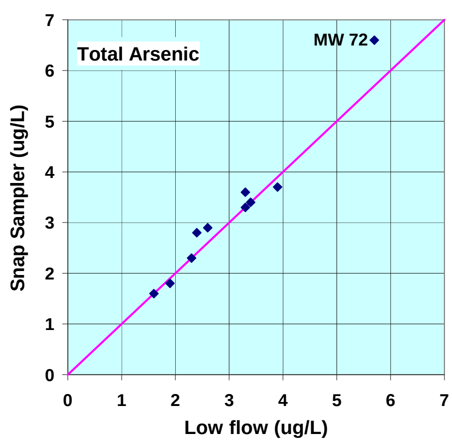


Figure 5-21. Comparison between the Snap Sampler and low-flow sampling for As.

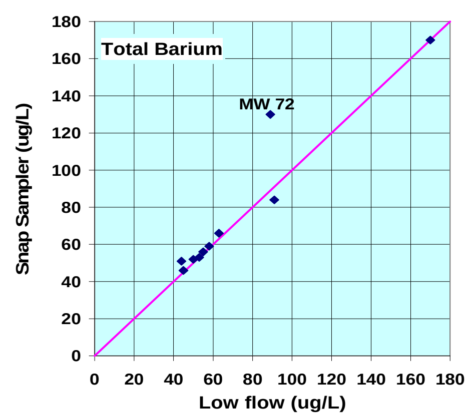


Figure 5-22. Comparison between the Snap Sampler and low-flow sampling for Ba.

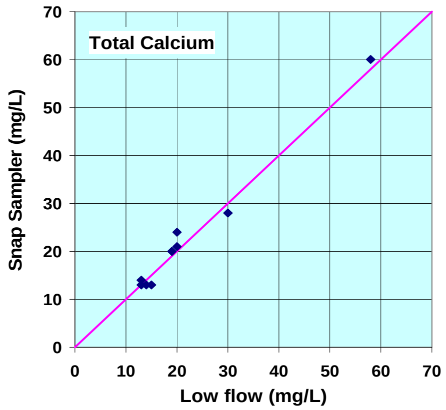


Figure 5-23. Comparison between the Snap Sampler and low-flow sampling for Ca.

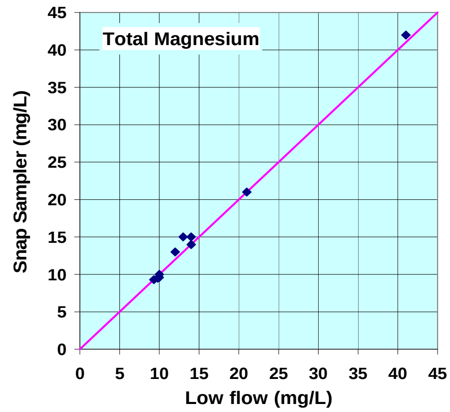


Figure 5-24. Comparison between the Snap Sampler and low-flow sampling for Mg.

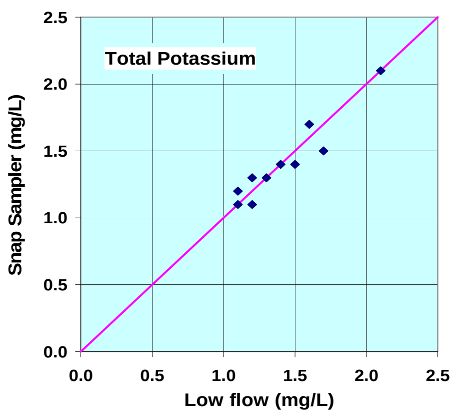


Figure 5-25. Comparison between the Snap Sampler and low-flow sampling for K.

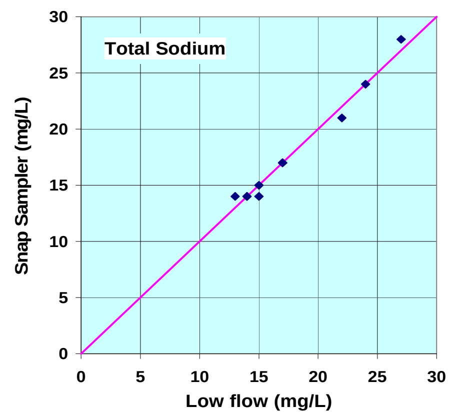


Figure 5-26. Comparison between the Snap Sampler and low-flow sampling for Na.

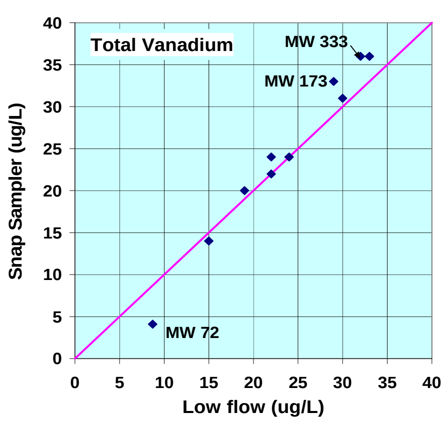


Figure 5-27. Comparison between the Snap Sampler and low-flow sampling for V.

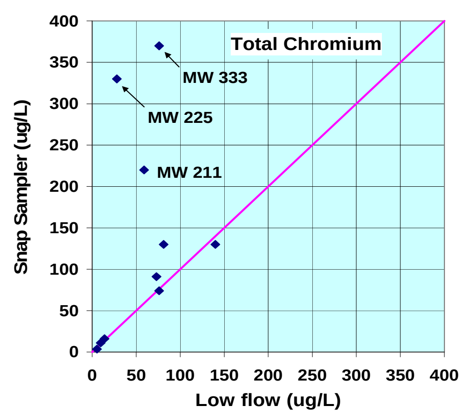


Figure 5-28. Comparison between the Snap Sampler and low-flow sampling for Cr.

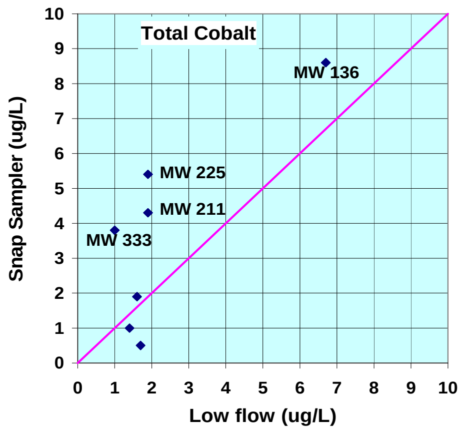


Figure 5-29. Comparison between the Snap Sampler and low-flow sampling for Co.

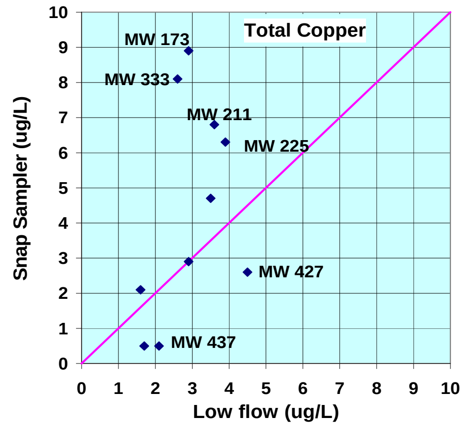


Figure 5-30. Comparison between the Snap Sampler and low-flow sampling for Cu.

However, even though there also was very poor agreement between the duplicate samples for Fe and Mn, there were statistically significant differences between the sampling methods for these analytes (Appendix E6). Analyses using a linear least-fit model (Table E3) showed that more than 91% of the variance in the Mn data could be explained by a linear model and that the slope was significantly greater than 1.0. Thus, for Mn, concentrations were significantly higher in the Snap Sampler samples compared with the low-flow samples. Concentrations of Fe were also significantly higher with the Snap Sampler although, the slope was not significantly different than 1.0 (most likely due to the variability in the data).

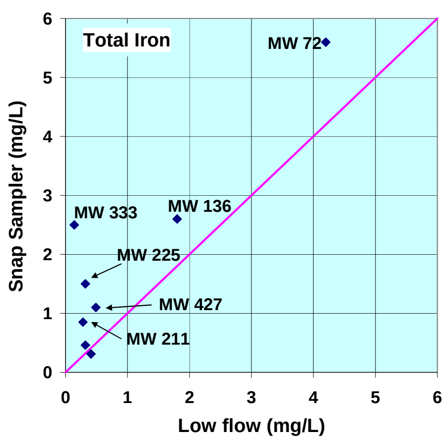


Figure 5-31. Comparison between the Snap Sampler and low-flow sampling for Fe.

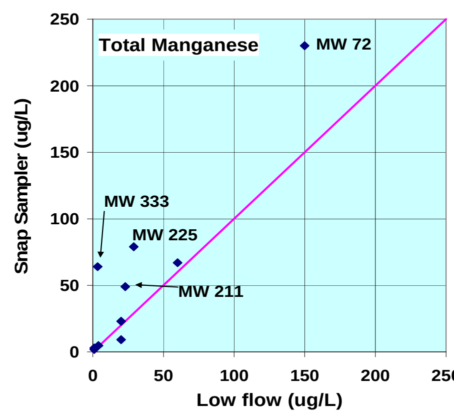


Figure 5-32. Comparison between the Snap Sampler and low-flow sampling for Mn.

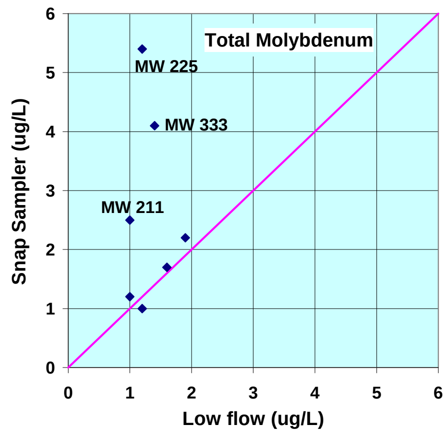


Figure 5-33. Comparison between the Snap Sampler and low-flow sampling for Mo.

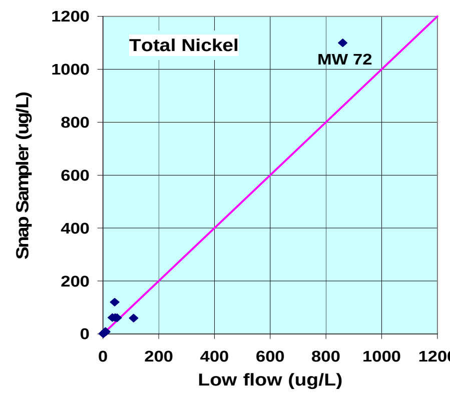


Figure 5-34. Comparison between the Snap Sampler and low-flow sampling for Ni.

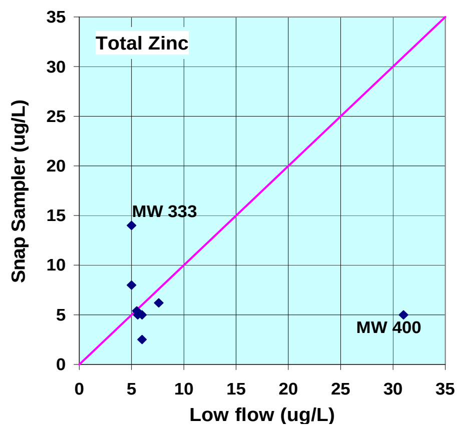


Figure 5-35. Comparison between the Snap Sampler and low-flow sampling for Zn.

5.8.3.2.3 Analysis of the data on a well-by-well basis

Examination of Figures 5-28 through 5-35 reveals that concentrations of some of the analytes tended to be higher in the Snap Sampler samples than in the low-flow samples in some wells. These relationships are summarized in Table 5-19 for analytes where there was a difference of a factor of two or more (and analyte concentrations were not at the reporting level).

This table shows that the most problematic wells were 211, 225, and 333. In most cases the concentrations were higher in the Snap Sampler samples than in the low-flow samples. Wells 211, 225, and 333 consistently had higher concentrations of Cr, Co, and Mn. However, it should be noted that the variability between the replicate field samples was poor for these analytes and that Co concentrations were also near the reporting limit where variability is generally greater.

5.8.3.2.4 Discussion

In our field notes (Table E7), we noted that the Snap samples from most of the wells had particulates, either black or orange, or pieces of rusted casing or screen, or both. This included wells 72, 136, 173, 225, 333, 427, and 1065. The various types of debris in the samples can be seen in Figures 5-36, 5-37, and 5-38. Also, although we did not note the presence of particles in samples from two of the other three wells (211 and 437), we can't rule out the possibility that those samples also had particles. (The sampling period was very busy and it is possible that we failed to make a note of the presence of particles in the samples from these wells.) In contrast, the samples from well 400 can be seen in Figure 5-39 and did not appear to contain any particulate matter.

Table 5-19. Relationships between analyte concentrations in wells where there was poor agreement between the sampling methods.

Well #	Analyte	Relationship
72	V	LF> SS
173	Cu	SS > LF
211	Cr	SS > LF
	Co	SS > LF
	Mn	SS > LF
225	Cr	SS > LF
	Co	SS > LF
	Mn	SS > LF
333	Cr	SS > LF
	Co	SS > LF
	Cu	SS > LF
	Fe	SS > LF
	Mn	SS > LF
	Mo	SS > LF
	Zn	SS > LF
400	Zn	LF> SS
427	Fe	SS > LF

Analytes in shaded boxes were above but near the reporting limit.

We believe that the orange precipitate was created when all the sampling equipment was placed in the well. This installation apparently agitated and oxygenated the well, and this formed hydrous iron oxides that then settled on the inside sloping wall of the Snap Sampler bottle and the spring (Fig. 5-38) and remained there until the Snap Sampler bottles were closed three weeks later. We believe that the larger pieces of orange material were rusted well screen that had broken off (as noted in wells 173 and 225). Concentrations of total iron were higher in the Snap Sampler samples than the low-flow samples for two of the wells where particles were found: i.e., wells 333 and 427. In contrast, total iron con-

centrations were below the detection limit for wells 400 and 437, where particulate matter had not been observed.

Figure 5-36. Photo of Snap Sampler samples showing black particles and piece of rusted casing (inside VOA vial).

Figure 5-37. Top of RGC sampler showing deposits of large black and orange particles.

Figure 5-38. Snap Samplers containing an orange precipitate.

Figure 5-39. Snap Sampler with no apparent debris in sampler (well 400).

The black particles may have been some type of biological film or could have been manganese oxides that were formed at the same time as the hydrous iron oxides. The presence of Mn oxides might explain the elevated levels of these analytes in some of these wells. Total Mn concentrations were higher in the Snap Sampler than in the low-flow samples in three wells: 211, 225, and 333. The presence of particulate Mn would explain the elevated concentrations of total Mn in these wells, where dissolved concentrations were at or near the reporting limit. In contrast, for the Snap Sampler samples from well 72, the dis-

solved and total concentrations of Mn were the same. The same was also true for the low-flow samples. This indicates that the higher bias associated with the Snap Sampler in this well was caused by the presence of dissolved Mn.

Concentrations of Co were also slightly higher in wells 211, 225, and 333. Elevated concentrations of this analyte may have resulted from coprecipitation with the hydrous iron or manganese oxides, or both. In contrast, several of the elements, including Ba, Ca, Mg, K, and Na, are highly soluble and not subject to inclusion in hydrous oxide precipitates.

Most of the wells used in this study were constructed with PVC casings and had slotted stainless steel screens; the type of stainless steel was not specified (Table E8). The one exception was well 72, which had low-carbon steel casing and screen. The composition of low carbon steel is primarily iron, the carbon content is between 0.5 and 0.30%, and the Mn content ranges between 0.40 and 1.5%. Components of type 304 stainless steel (the most commonly used steel in monitoring wells) include Cr (minimum 18%), Ni (minimum 8%), Mn (2% maximum), C (0.08%), and Fe (remainder). Type 316 stainless steel, which is used in more corrosive environments, also contains Mo (minimum of 2%). Other components include Cr (minimum of 16%), Ni (minimum of 10%), carbon (maximum of 0.03%), and Fe (remainder).

Well 72 had much higher concentrations of dissolved Fe and Mn than any of the other wells, most likely indicating leaching of these constituents from the low-carbon steel casing and screen. Leaching of Ba, Cd, Cr, Cu, Fe, Ni, and Pb has been also been shown to occur from stainless steel 304 and 316 well casings and screens (Hewitt 1992, 1994). Therefore, we believe that, for some wells, the elevated concentrations of Cr, Cu, Fe, Mo, Mn, and Ni reflect probable leaching of metal constituents from and corrosion of the stainless steel well screens. All the wells, with the exception of two anoxic wells (72 and 136), had sufficient DO levels to be considered a corrosive environment (Table E9.) Hewitt (1992) also found that stainless steel casings and screens leached metal constituents even under low DO conditions. Therefore, we believe that leaching of metal constituents from the screens occurred in these wells as well.

The presence of pieces of rusted material in some of the Snap Sampler samples and on some of the RGC samplers, and the resilient high turbidity values during low-flow sampling (that did not respond to prolonged pumping) may indicate that in some wells, the well screens were corroded and that this led to an increase in the slot size of the screens. An increased slot size would allow fines to enter these wells, thereby elevating the presence of particle-bound analytes.

5.8.3.2.5 Conclusions for the total inorganic analytes

Given the poor reproducibility found for the field duplicate samples with both sampling methods for total Cr, Co, Cu, Fe, Mn, and Mo, and the apparent leaching of constituents from the screen (and casing in the case of the low-carbon steel well no. 72), we would not recommend using either sampling method to sample wells for these analytes if the wells are constructed with low-carbon steel or stainless steel casings or screens.

For those analytes where the precision of the replicates was within the recommended guidelines, there were no statistically significant differences between the two sampling methods. This includes As, Ba, Ca, Mg, K, Na, Zn, chloride, and sulfate.

For the other analytes (Cr, Co, Cu, Fe, Mn, and Mo), where the reproducibility of the replicate field samples was poor, there were no statistically significant differences between the two sampling methods for Cr, Co, Cu, and Mo. However, there was a statistically significant difference between low-flow sampling and the Snap Sampler for total Fe and Mn, with higher concentrations in the Snap Sampler. In addition, a well-by-well analysis of the data reveals that the Snap Sampler samples had substantially higher concentrations of constituent metals than low-flow sampling in some wells (i.e., well numbers 211, 225, and 333).

We believe that there may have been several causes for these differences. These included: 1) leaching of metal constituents of the stainless steel (and low-carbon steel in one instance) screens; 2) corrosion of the well screen allowing fines to enter the well; and 3) installation of the sampling equipment in the well, which caused agitation of the wells and resulted in formation of hydrous iron and possibly manganese oxides.

6.0 PERFORMANCE ASSESSMENT

6.1 PERFORMANCE ASSESSMENT OF THE SNAP SAMPLER

Table 6-1 summarizes the findings for the performance objectives for the Snap Sampler. Generally, the Snap Sampler met the performance criteria.

Table 6-1 Performance of the Snap Sampler.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative			
1. Ability to sample a range of contaminants at site	*Adequate sample volume for all analyses*	*Similar detection capabilities (as with low-flow sampling)*	Yes
2. Reproducible data	*Analyte data for replicate samples*	*Among replicate samples, a %RPD of 25% or less, or equal to or better than that for low-flow samples*	Yes for VOCs, dissolved inorganics, and total non-metal ions; Issues with some total metals for Snap Sampler *and low-flow sampling*
3. Agreement between sampling methods for analytes of interest	*Analyte concentrations for each sampling method for all wells*	• *Lack of statistically significant differences* • *Lack of bias*	Yes, with two exceptions: total Fe and total Mn
4. Reduced sampling time	*Field records of activities at each well*	*Less time needed to sample a well*	Yes
5. Less costly sampling method	• *Records of the costs for equipment and supplies* • *Field record of technician's time*	*Cost savings of at least 25%*	Yes
Qualitative			
1. Ease of use	*Field records of activities at each well*	*Technician able to learn the procedure with relative ease.*	Yes
2.Ease of use	*Field records of activities at each well*	*Few problems requiring second attempt to sample the well*	Yes (providing manufacturer's directions were followed)
3. Ease of Use	*Feedback from field technician*	*Operator acceptance*	Yes

6.1.1 Ability to sample a range of contaminants at the site

This is the first site where we have used the Snap Sampler to collect samples for a number of analyte types. Specifically, we collected samples for VOCs, dissolved metals, total metals, total anions, and dissolved and total Fe (2) for field analyses. This required that we collect a minimum of 300 mL of sample. In addition, we collected the typical QA/QC samples, which included field duplicates and MS and MSD samples. In all cases, we were able to collect the sample volume needed for these analyses. Because the sample volumes were the same for the Snap Sampler and low-flow sampling, the detection capability was the same for the two sampling methods.

6.1.2 Reproducible data

The guideline for this objective was that the % RPD between the field replicate samples either be 25% or less, or be equivalent to (or better than) that for the low-flow samples. These requirements were only for analytes where the concentrations were greater than (or equal to) three times the reporting limit.

With only a few exceptions, the replicate data were within the guidelines for the Snap Sampler for the VOCs, dissolved inorganics, and total non-metal ions. However, this was not the case for the total metals. The RPD exceeded the guideline for both the Snap Sampler *and low-flow sampling* for Cr, Fe, and Mn. This was also true for *both* sampling methods for Co, Cu, and Mo; however, concentrations of these analytes were at or near the reporting limit. The RPD also exceeded the guideline for V with the Snap Sampler samples**.**

Given the poor reproducibility found for the field duplicate samples with *both* sampling methods for total Cr, Co, Cu, Fe, Mn, and Mo, and the apparent leaching of constituents of the screen and casing (in the case of the low-carbon steel well, no. 72), we would not recommend using wells with stainless steel casings or screens for sampling for these analytes using either sampling method.

6.1.3 Agreement between analyte concentrations for the two sampling methods

Two types of statistical analyses were used to determine if there was good agreement between analyte concentrations obtained with the passive sampling methods and low-flow sampling. First, the data were tested to determine if there was a lack of statistically significant differences between the sampling methods. This was determined by using either a paired-*t*-test (or its non-parametric equivalent) to compare the two sampling methods, or a Repeated Measures Analysis of Variance test (RM-ANOVA) (or its non-parametric equivalent) to compare all three sampling methods. Good agreement between the sampling methods was also determined by testing to see if there was a lack of bias between the low-flow and passive sampling methods. Specifically, we determined the lack of bias by using a linear regression of the passive sampler data (for each sampler separately) vs. the low-flow data. This told us if 1) there was a statistically significant linear relationship, and 2) the slope of the line was significantly different from 1.0. A slope of 1.0 indicates that there is no significant bias between the two data sets, i.e., there is a one to one correlation between the concentrations for the two methods.

Generally, there was excellent agreement between analyte concentrations in the Snap Sampler and low-flow sampling and these relationships were linear with the slopes equal to 1.0 (as discussed in detail earlier). There were no statistically significant differences between analyte concentrations in the Snap Sampler and the low-flow sampling for the VOCs, dissolved inorganics, total non-metal anions, and most of the total metals and metalloids. The exceptions to this were for total Fe and total Mn, where concentrations were significantly higher in the Snap Sampler samples.

We believe that there may have been several causes for the elevated concentrations of total Fe and Mn: 1) leaching of metal constituents of the stainless steel screens and low-carbon steel casing and screen; 2) corrosion of the well screens allowing fines to enter the well; and 3) an experimental artifact caused when all the sampling equipment was placed in the well. When the equipment was added to the well, this caused agitation that elevated the level of fines in the well and may have also caused the formation of hydrous iron, and possibly manganese oxides.

6.1.4 Reduced Sampling Time

Field records of the sampling time were kept for all the sampling events and were used to project the time required to sample a similar site with 50 wells. Those calculations indicated that the time needed with the Snap Sampler was less than one fourth that needed for low-flow purging and sampling. Specifically, we calculated that approximately 54 hours would be needed to sample the site with the Snap Sampler vs. 240 hours using low-flow purging and sampling.

6.1.5 Less Costly Sampling Method

The other primary performance objective that was met was that this sampling method provide a minimum cost savings of 25% (over low-flow purging and sampling). To determine this, accurate records of all the expenses associated with the equipment and supplies and of the technician's time had to be kept for each of the sampling methods. The detailed cost analyses can be found in section 7.0.

6.1.6 Ease of Use

All three qualitative measures of this performance objective were met. The developer had previously redesigned the sampler to make assembly of multiple samplers on the same trigger line more fool-proof. Specifically, the up direction on the samplers was clearly marked and the connecting pieces were fabricated so that it was impossible to assemble a string of samplers incorrectly (i.e., upside down). As a result, all of the field crew was able to assemble the samplers with relative ease and even our new field technician was able to learn the procedure quickly. The only instances where the samplers had to be redeployed were when the manufacturer's directions for cocking them prior to deployment were not properly followed. This can no longer happen with the redesigned samplers (i.e., the manufacturer added a stop so that the pin cannot be cocked too far open).

6.2 PERFORMANCE ASSESSMENT OF THE RGC SAMPLER

Table 6-2 summarizes the findings for the performance objectives for the RGC sampler. Generally, this sampler met the performance criteria and was easy to use. However, the applicability of this sampler is more limited than the Snap Sampler because it can only be used for dissolved constituents.

Table 6-2 Performance objectives for the RGC sampler.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative			
1. Ability to sample a range of contaminants at site	*Adequate sample volume for all analyses*	*Similar detection capabilities (as with low-flow sampling)*	Yes, but cannot be used to sample for total inorganic analytes
2. Reproducible data	*Analyte data for replicate samples*	*Among replicate samples, a % RPD of 25% or less, or equal to or better than that for low-flow samples*	Yes, with one exception (1 analyte in 1 well)
3. Agreement between sampling methods for analytes of interest	*Analyte concentrations for each sampling method for all wells*	• *Lack of statistically significant differences* • *Lack of bias*	Yes for some VOCs and dissolved inorganics but not all[1]
4. Reduced sampling time	*Field records of activities at each well*	*Less time needed to sample a well*	Yes
5. Less costly sampling method	• *Records of the costs for equipment and supplies* • *Field record of technician's time*	*Cost savings of at least 25%*	Yes
Qualitative			
1. Ease of use	*Field records of activities at each well*	*Technician able to learn the procedure with relative ease.*	Yes very easy to use
2.Ease of use	*Field records of activities at each well*	*Few problems requiring second attempt to sample the well*	Yes
3. Ease of Use	*Feedback from field technician*	*Operator acceptance*	Yes

[1] There were no statistically significant differences between the concentrations in the RGC samplers and low-flow samples for carbon tetrachloride, cDCE, As, Ca, Cr, Ni, and V. Statistically significant differences were found between the two sampling methods for TCE, Ba, Mg, K, and Na. Also, MTBE and acetone were only detected in the RGC samplers.

6.2.1 Ability to sample a range of contaminants at the site

Because of the small pore size of the RGC membrane, particles are prevented from entering these samplers, and this meant that the RGC samples could not be analyzed for total anions, total metals, or total field Fe(2). Because most risk assessors are interested in the total contaminant load, this could prevent the use of this sampler for risk analyses. The RGC sampler provided adequate sample volume for the analyses of those analytes that

could be measured, and, thus, the sensitivity of those analyses was comparable with low-flow sampling.

6.2.2 Reproducibility of the RGC sampler

When the analyte concentrations were not near the reporting limit, the replicate field data for the RGC samplers were within the guideline (< or = 25% RPD) for the VOCs and for the dissolved inorganic analytes with one exception: in one of four wells where the RPD for K was 27%.

6.2.3 Agreement between analyte concentrations of the two sampling methods

As mentioned previously, only concentrations of VOCs and dissolved inorganics could be compared for the RGC sampler. For the VOCs, the RGC sampler recovered equivalent concentrations of carbon tetrachloride and cDCE. In contrast, concentrations of MTBE and acetone were detected in the RGC samples but not the low-flow or Snap Sampler samples or the RGC equipment blanks. We were not able to determine why this was the case for MTBE but suspect that acetone may have been a contaminant in the bottled distilled water that was purchased on site (for the use with only this sampler but was never tested). In contrast, concentrations of TCE were significantly lower in the RGC samplers than those collected using low-flow sampling (but not the Snap Sampler).

There was good agreement between the concentrations of dissolved As, Ca, Cr, Ni, and V. However, concentrations were slightly significantly higher for Ba, Mg, K, and Na in the RGC sampler. This was discussed in more detail earlier.

6.2.4 Reduced Sampling Time

Another measure of performance is that the sampling method be less time consuming. This was determined from records that were kept in the field notebook. Records included set-up time, sampling time, sample processing time, and site-clean up time. Even though this method requires two trips to the field and time to assemble the sampler, this performance standard was easily met. We calculated that the total labor time for sampling this site (with 50 wells) would be 75 hours with the RGC sampler vs. 240 hours with low-flow sampling.

6.2.5 Less Costly Sampling Method

The other primary quantitative performance objective is that the sampling method provide a minimum of a 25% cost savings over low-flow purging and sampling. This was more than met with a projected cost savings of 67% for over 10 years (for a similar site with 50 wells).

6.2.6 Ease of Use

Other measures of the performance of the passive samplers included ease of use, and faster sampling time. Ease of use included the technician being able to learn the procedure relatively easily, there being few problems requiring a second attempt to sample the well, and operator acceptance. The first two of these criteria were determined from records in the field notebook. Operator acceptance was determined from feedback from

the field technicians. This sampler was very easy to use and was well liked by the field crew. The only issue was in one well where it fell off the line. That sampler was eventually recovered but it was badly torn by the hook used to recover it.

7.0 COST ASSESSMENT

To determine the cost savings associated with the Snap Sampler and the RGC sampler compared with low-flow purging and sampling, the time spent on each sampling task (including low-flow sampling) was recorded in the field notebook. The costs of the equipment and other materials used with each of the three sampling methods were based upon current prices. This information was used to determine the costs associated with each of the sampling methods.

For low-flow sampling this included the costs of dedicated pumps and tubing, the costs of the ancillary equipment and other materials, and the time (which is a cost) associated with purging the wells until the field parameters stabilized.

For the RGC samplers, total costs included the materials and time required to make the samplers, and the time needed to install the samplers, recover them from the wells, and process the samples. Because of the short life expectancy of these samplers, the cost of this sampler included two trips to the field; one to deploy the samplers and one to recover them.

For the Snap Sampler, there were initial capital costs from purchasing these samplers, costs for bottles, and the costs associated with deploying and recovering the samplers and processing the samples. For routine monitoring, new Snap Sampler bottles would be deployed at the end of a sampling event, and the samplers would then remain in the wells until the next scheduled sampling event. This eliminates the need for a second trip to the field for each sampling event as seen with the RGC samplers.

The costs associated with waste disposal for all three sampling methods were also included in the overall costs of the three sampling methods.

7.1 COST MODEL

Cost models for long-term monitoring of a similar site with 50 monitoring wells and quarterly sampling over 10 years were developed for low-flow purging and sampling, the Snap Sampler, and the RGC sampler (Tables 7-1, 7-2, and 7-3, respectively). For each sampling method, the cost model consists of two cost elements: the initial start-up costs and the quarterly sampling costs. Both cost elements consist primarily of two elements: labor and materials (equipment and supplies). Labor for each sampling method was determined by recording in the field notebook the time needed for each task conducted in the field. Material costs were determined by current purchase prices or rental costs.

7.1.1 Initial Start-up Costs

Labor costs for the initial start-up consist of the time needed to plan field work and order necessary equipment, and the time needed to install the equipment in the wells.

The initial start-up costs for materials included all one-time purchases of equipment and supplies needed for the technology. As an example, for low-flow sampling this would

include the purchase prices for bladder pumps, sampling tubing, generator, air compressor, flow-through cell, and purge parameter equipment.

7.1.2 Quarterly Sampling Costs

Labor costs for quarterly sampling varies with the sampling device but can include the time needed to make the samplers (the RGC samplers), deploy the samplers, collect the samples (including purge time for low-flow sampling), clean up the site, and dispose of wastes and waste water.

Common quarterly sampling costs can include the following: the materials needed to fabricate the disposable RGC samplers, the Snap Sampler bottles and holders, and supplies needed for low-flow sampling (such as gasoline, calibration standards for purge equipment, distilled water, etc.).

Table 7-1. Cost model for low-flow sampling: site with 50 wells, and quarterly sampling for 10 years.

Cost Element	Data Tracked During the Demonstration	Costs	
Initial Start-up	Labor: initial planning fieldwork, purchasing equipment and supplies	Project technician, 52 hr	$3,120
	Equipment and supplies: One-time purchases (50 wells)	Materials[1]	$52,725
	Installation costs	Project technician, 110 hr	$6,600
		Incidentals	$15
Quarterly Sampling Costs	Supplies	Materials	$285
		Incidentals	$15
	Labor: sampling 50 wells and waste disposal	Project technician, 240 hr	$14,400
Long-term Monitoring Costs	Total Costs, no inflation	Annual sampling cost	$58,700
		Total costs after 1 year	$117,475
		After 10 years	$645,750
	Cumulative Costs, assuming OMB's 2.2% annual inflation	After 1 year	$117,475
		After 10 years	$707,400

Table 7-2. Cost model for sampling using Snap Samplers: site with 50 wells, and quarterly sampling for 10 years.

Cost Element	Data Tracked During the Demonstration	Costs	
Initial Start-up	Labor: initial planning fieldwork, purchasing equipment and supplies	Project technician, 34 hr	$2040
	Materials: One-time purchases of Snap Sampler equipment (50 wells)	Materials[1]	$81,623
	Installation costs	Project technician, 37.3 hr	$2250
		Incidentals	$10
Quarterly Sampling Costs	Equipment :Snap Sampler bottles	Materials	$4320
	Also needed for initial installation	Incidentals	$12
	Labor: sampling 50 wells and minimal waste disposal	Project technician, 38.7 hr	$2332
Long-term Monitoring Costs	Total Costs, no inflation	Annual sampling cost	$26,610
		Total cost after 1 year	$116,840
		After 10 years	$356,320
	Cumulative Costs, assuming OMB's 2.2% annual inflation	After 1 year	$116,840
		After 10 years	$384,300

Table 7-3. Cost model for sampling with RGC Samplers: site with 50 wells, and quarterly sampling for 10 years,

Cost Element	Data Tracked During the Demonstration	Costs	
Initial Start-up	Labor: initial planning fieldwork, purchasing equipment and supplies	Project technician, 42 hr	$2520
	One time purchase of equipment and supplies	Materials[1]	$2300
Quarterly Sampling Costs	Equipment :RGC sampler materials	Materials	$614
	Labor: making samplers	Project technician, 24 hr	$1440
	Labor: deploying samplers	Project technician, 25 hr	$1500
	Labor: sampling 50 wells and minimal waste disposal	Project technician, 26.4 hr	$1584
	Miscellaneous		$15
Long-term Monitoring Costs	Total Costs, no inflation	Annual sampling cost	$20,525
		Total cost after 1 year	$25,345
		After 10 years	$211,000
	Cumulative Costs, assuming OMB's 2.2% annual inflation	After 1 year	$25,345
		After 10 years	$232,000

7.2 COST DRIVERS

Cost drivers are factors that are unique to the sampling technology that can substantially impact the cost of using that technology.

7.2.1 Cost Drivers for the Snap Sampler

We concluded that the following items compose the major cost drivers for the Snap Sampler. (Please note that all the values used in this analysis are adjusted for inflation.)

- **The number of analytes.** Increasing the number of analytes that need to be sampled can increase the number of Snap Sampler bottles and holders that are needed when larger bottles can't be substituted instead. This can drive up the cost of sampling. As an example, if we had also sampled for explosives, we would have needed three 350-mL bottles rather than three 125-mL bottles. This would have given the needed volume for the inorganic analytes (total and dissolved) and a 500-mL sample for the explosives analyses. As the price for the 350-mL bottles and bottle holders is the same as that for the 125-mL bottles and bottle holders, this would not have driven up the cost of sampling. This would have also provided us with the capability to detect fairly low levels of these analytes. However, if we had needed a full liter of sample for analyses of lower levels of explosives, then we would have needed an additional 350-mL bottle, and the additional cost for LTM would have been about $44,410 over 10 years. However, the estimated cost savings would still be 39.4%, which more than exceeds our performance objective of 25% (Table 3-1).
- **Sample volume requirements.** Large sample volume requirements can also increase the number of sampler bottles and bottle holders needed. The previous example shows that larger sample volume requirements can add to the cost of using the Snap Sampler.
- **Depth of the sampling interval.** At this site, the wells were relatively deep and required an electronic trigger. However, as an example, if the wells had been only 40 ft deep, the total LTM cost for 10 years would have been $353.5k. The cost savings would have been increased to 50%, as compared with the 45.7% cost savings noted for the deeper wells at this site.
- **Reconditioning of the wells.** It is not known how often the wells should be redeveloped or reconditioned with passive sampling methods. Given time and financial constraints, this is often an issue that currently is disregarded by sampling teams using conventional sampling methods. However, even if one assumed that the wells sampled with the Snap Sampler will need to be reconditioned every 10 years, the estimated cost savings from using this technology would still be over 25%. The projected long-term cost would be about $422.3k, with an estimated cost savings of 40.3% over low-flow sampling (assuming no well conditioning).
- **Replacing Snap Sampler hardware.** Given the materials used in the Snap Sampler (mostly rigid plastics), we would not anticipate that the equipment would require replacement during the 10-year deployment period. However, even if all of the equipment had to be replaced every 5 years, the estimated 10-year LTM cost

using the Snap Sampler would be about $466k, and the cost savings would still be 34.2%, which still exceeds the performance objective of 25%.

7.2.2 Cost Drivers for the RGC Samplers

Because the costs of the materials used to make the RGC samplers are so inexpensive, increasing the number of analytes or sample volume does not substantially increase the cost of LTM with RGC samplers. However, reconditioning the wells would reduce the LTM cost savings from 67.2 to 61.9%.

7.3 COST ANALYSIS

For our cost analysis, our typical site consisted of 50 wells that were sampled quarterly over 10 years. The depth of the wells used for the calculations was the average depth of the 10 wells sampled at McClellan, i.e., 154 ft. This site was sampled for the same suite of analytes as in this demonstration, i.e., VOCs and total and dissolved inorganics, including separate samples for the analyses of anions and field analyses of total and dissolved iron. Power was not available at most of the sites so the price of a generator (to power the equipment) had to be factored in the cost analyses for the low-flow sampling.

To perform the cost analyses for low-flow purging and sampling, the Snap Sampler, and the RGC sampler, the following assumptions were made:

- Standard minimum volume requirements were used to determine the sample volume needed for analyses.
- The RGC samplers were constructed by the field technician.
- An additional trip to the field for deployment would not be necessary for the Snap Sampler as it would routinely be re-deployed after each sampling event.
- An additional trip to the field for deployment would be necessary for the RGC samplers because of their relatively short (*in-situ*) shelf life. This redeployment time was included in the labor needed for each sampling event.
- Calculations for labor for low-flow sampling are based upon two individuals conducting the sampling. This is current industry practice and given the heavy equipment that had to be moved from site to site, this seems to be a reasonable assumption.
- Only one individual was figured in calculating the labor needed to collect samples using either the Snap Sampler or the RGC sampler. This was because the samplers were easy to deploy and recover, and there was no heavy equipment to move that would have necessitated having a second person to assist.
- This estimate does not include any cost for replacing the Snap Sampler equipment such as sampler holders or trigger lines.
- This estimate does not include any reduction in the cost of the Snap Sampler equipment based on economy of scale. The price of Snap Sampler equipment would be lower if there were a larger demand for it and manufacturing was on a larger scale.
- The average purge time in this study was used to calculate the sampling time for low-flow sampling at this site.

- This estimate does not include any cost for replacing the pumps or other equipment used for low-flow sampling or for the Snap Samplers. (The RGC samplers are disposable.)
- No per diem costs were factored into the cost analyses. It was assumed that the sampling personnel would be on site.
- No reconditioning of the wells was factored into any of the three sampling methods.

Below (Table 7-4) is an itemized list of some of the items used for the cost analyses.

Table 7-4. List of the cost basis for sampler-unique items.

Item	Unit basis	Cost ($)
Labor	$ per hour	60.00
Snap Sampler		
Snap bottles (any size)	$ per bottle	16.00
Holder (any size)	$ per holder	165.00
Trigger line, fabrication fee	$ per trigger line	85.00
Electronic trigger switch	$ each	175.00
Electric trigger line	$ per foot	1.75
Down-hole actuator	$ each	32.50
28-V batteries, charger, case	$ each	560.00
Docking station	$ each	42.00
RGC Sampler		
Stainless weight	$ each	1.00
Membrane	$per 10-m roll	202.00
Rigid inner body material	$ per 42-in. tube	5.00
Protective outer netting	$ total	40.25
Line	$ total	129.99
Docking station	$ each	42.00
Nitrogen gas	$ per tank	20.00
Low-Flow Sampling costs		
Bladder pump, 3/4 in., stainless steel	$ per pump	500.00
Sample tubing, 1/4 in. Teflon x 1/4 in. bonded	$ per foot	1.00
Generator	$ each	1100.00
Air compressor	$ per compressor	180.00
Pump controller	$ per controller	1760.00
Water quality meter and flow cell	$ per meter	5850.00
Nylon-coated wire line	$ per foot	1.00

The total estimated cost for sampling 50 wells quarterly for 10 years using low-flow sampling was projected to be $707k (Table 7-1). This estimate was based upon the indus-

try norm of a field crew of two. The total initial investment for equipment was nearly $53K and the labor costs for annual sampling was approximately $59k.

The estimated cost for the same number of sampling events using the Snap Sampler came to $384K (Table 7-2), and the cost savings with this technology were 46% when compared with low-flow sampling. While the initial investment for equipment was more than for low-flow sampling ($81.6k vs. $53k), the cost savings were derived from the reduced labor costs. The estimated labor costs for annual sampling were $9.3k, vs. $59k for low-flow sampling. As mentioned previously, this estimate assumed that because there was no heavy equipment that needed to be moved from well to well and because of the ease of sampling with this device that only one person would be needed to sample a well.

The estimated cost for using the RGC sampler was considerably less at this site, $232k (Table 7-3). Again, a field crew of one was assumed. This translates into a cost savings of 67% when compared with low-flow purging and sampling. This method significantly reduced both equipment and labor costs over low-flow sampling. This method requires minimal initial capital investment ($2.3k), and the materials need to make the samplers cost only $2.5k per year (without factoring in inflation). With respect to labor, even with including the labor associated with making the samplers for each sampling event, the labor costs per year were only $18.1k vs. $59k with low-flow sampling. The cost savings would have been even greater if a second trip to the field was not needed for this sampler. (The second trip to field is needed because the membrane cannot be left for quarterly sampling events because it can biodegrade if left in the well for that long.) However, we want to caution that these cost savings are misleading because it is not possible to sample for all the same suites of analytes as with the Snap Sampler or low-flow sampling. Only dissolved inorganics and organics can be determined using a RGC sampler, while the Snap Sampler and low-flow purging and sampling can be used to collect samples for total inorganics (such as total metals) and for total organics, which would also include particle-borne hydrophobic organics such as PCBs.

Clearly, reduced labor is the primary driver for the cost savings associated with passive sampling methods.

8.0 IMPLEMENTATION ISSUES

Although, this demonstration and our previous studies (Parker et al. 2007, 2009) have shown that there does not appear to be any bias associated with using this sampler for organic and most inorganic analytes, there are several issues that need to be addressed to promote greater acceptance of this technology.

8.1 REGULATORY ISSUES

A survey sent to the ITRC's state POCs confirmed that there are some regulatory barriers (statutes, regulations, or guidance) that either prohibit or impede the use of passive sampler technologies (ITRC 2007). Of the 16 states responding to the survey, 25% believed their state prohibited use of passive sampling technologies because they required either three-well-volume purging or low-flow purging and sampling. Other states require that the wells be purged, which precludes using passive sampler technologies. However, all states appear receptive but lean towards a demonstration to verify their reliability. New Jersey was the only responding state that has published guidance on using a specific passive sampling technology for groundwater.

To address regulatory concerns, the ITRC Passive/Diffusion Sampling Team has been proactive in promoting passive sampling technologies during the past decade and has published several guidance documents on various passive sampling technologies. In 2001, they published a user's guide for the PDB samplers for sampling VOCs (ITRC 2001), and in 2004 they published a technical regulatory guidance document for using PDB samplers for monitoring VOCs (ITRC 2004). In 2006, they published an overview document on 14 passive sampling technologies, including the Snap Sampler and the RGC sampler (ITRC 2006). In 2007, the team published a protocol document on the use of five passive samplers, including the Snap and RGC samplers (ITRC 20007). This document provides guidance on how to deploy and collect samples using these samplers, and on the advantages, applicability, and limitations of these technologies. All of these documents are available for free on the ITRC website (http://www.itrcweb.org/). ITRC also has provided, and continues to provide (as of 2010), a free internet training class on the use of these five sampling devices. An archived copy of the most recent training session is also available on the team website.

Also, ASTM D.18.21.04 (sample collection for groundwater monitoring) is developing a guide on the selection of passive sampling techniques.

8.2 END-USER CONCERNS

8.2.1 Snap Sampler

Based upon the findings in this demonstration and the one conducted at the former Pease AFB (Parker et al. 2009), it is not clear whether samples can be collected for some total metals, specifically total Fe and Mn. Clearly, inserting all the sampling equipment in the well elevated the turbidity in some of the wells but it is not clear whether this would occur if only the Snap Sampler were placed in the well. It is clear that neither stainless steel and other steel casings and screens should not be used if analyzing for total metal consti-

tuents such as Fe, Cr, Mn, etc., are of interest This was true whether low-flow purging and sampling or the Snap Sampler were used to collect the samples.

With respect to the Snap Samplers, probably the greatest concern with this technology has been the initial capital investment required. The cost analyses conducted in this report and in our previous demonstration at Pease AFB (Parker et al. 2009) clearly showed that even with this substantial initial capital outlay, substantial cost savings can be achieved with this technology. If this technology becomes more widely used, the price of the samplers and sampler bottles should decrease as manufacturing costs are reduced and cost savings would be larger. A related concern is whether the equipment would need to be replaced periodically, thereby driving up the cost of this technology. The cost analyses conducted for the *Cost Drivers for the Snap Sampler* section shows that even if all of the Snap Sampler equipment had to be replaced every 5 years, the cost savings would still exceed the 25% performance objective set out in Table 3-1 for this technology.

Another concern with this technology is its use for sampling a spectrum of analyte types. This demonstration was specifically designed to address that concern by sampling for a broad spectrum of analyte types. The *Cost Drivers for the Snap Sampler* section also demonstrated that even if another suite of analytes, such as explosives, were added that this would have minimal impact on the cost of the LTM.

A final concern is whether wells that are sampled with passive samplers will need to be reconditioned more often than wells that undergo active sampling such as low-flow purging and sampling. Although this issue is typically overlooked when active sampling methods are used, the cost analyses performed for the *Cost Drivers for the Snap Sampler* section also demonstrated that, even if the wells had to reconditioned once every 10 years, the cost savings still would exceed the 25% performance objective.

8.2.2 RGC samplers

It is important to point out that this sampler does not have as broad an analyte capability as either the Snap Sampler or low-flow sampling. RGC samplers can only be used to sample for dissolved constituents so this prevents its use for total analytes such as total metals or highly hydrophobic organic analytes. This most likely would be a concern for risk assessors.

One of the users' concerns is that the RGC sampler is currently not commercially available. As of this publication date, Columbia Analytical (maker of the PDB and RPP samplers) is considering manufacturing this device. However, the cost analyses also clearly demonstrated that huge cost savings can be achieved with this sampler, even when the cost of sampler construction is factored into the total cost of LTM.

Again, it is not known whether wells that are sampled with passive samplers will need to be reconditioned more often than wells that undergo active sampling such as low-flow purging and sampling. However, the cost analyses performed for the *Cost Drivers for RGC samplers* section clearly demonstrated that even if the wells had to be reconditioned

once every 10 years, the cost savings still would greatly exceed the 25% performance objective.

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APPENDIX B: ADDITIONAL METHODS

B.1 SAMPLE HANDLING AND DOCUMENTATION

B.1.1 Field Procedures

All sample bottles were labeled, placed in zip-lock plastic bags, and immediately placed on ice in a cooler. Waterproof sample container labels and waterproof permanent markers were used to label the samples. All samples were marked with the sampling date, sampling individual, whether they were filtered, and given a sample number that identified the site, well, and sampling method to the sampling personnel but not the laboratory. All sample collection information was recorded in a bound field notebook.

All samples were kept on ice until they were shipped to the laboratory for analyses; additional ice was added as needed and the melt water was drained from the plug on the bottom of the cooler. When the samples were ready to be shipped, they were placed on fresh ice, all chain-of custody forms were filled out, and the coolers were sealed prior to collection by the laboratory. The coolers were collected daily by a laboratory courier, and delivered to the laboratory within 1 to 2 hours.

B.1.2 Laboratory Procedures

Standard laboratory practices for handling the samples included proper receiving, log-in, and storage of field samples, and chain-of-custody documentation.

B.2 QUALITY ASSURANCE SAMPLING

To ensure data quality, standard QA/QC samples were taken. These included field duplicates, duplicate samples for matrix spikes and matrix spike duplicates, trip blanks, and equipment blanks.

During the course of the field sampling, duplicate samples were collected for all three sampling methods (low-flow, Snap, and RGC). For each sampling method and each analyte type, there were two out of ten field duplicate samples (i.e., the results from these analyses provide a measure of the precision [repeatability] of the field sampling methods).

Duplicate samples for spiked recoveries were collected for 5% (or one out 20) of the total number of samples for the purposes of preparing Matrix Spikes (MS) and Matrix Spike Duplicates (MSD). They were identified with the suffixes MS and MSD on the chain-of-custody forms. These samples were used to identify matrix effects on spiked analytes of known quantity, as well as the laboratory's precision in recognizing matrix effects.

Trip blanks were prepared by the contract laboratory using analyte-free reagent water. There was one trip blank per sampling day. Trip blanks were handled, transported, and analyzed using identical procedures as those used for the other groundwater samples.

B.2.1 Equipment Blanks

Because of time constraints with the field schedule, the blank sampler tests were not conducted until after we had returned from conducting the field study.

B.2.1.1 Equipment Blanks for the Snap Samplers

Two strings of Snap Samplers were prepared. Each string consisted of a 12-in. long manual trigger line attached to two 125-mL samplers and a 40-mL sampler. We suspended each of the sampler lines in a separate polypropylene pipette cleaners that were filled with fresh deionized water (DI). The pipette washers had been previously cleaned with detergent and hot water, rinsed until there were no suds, and then rinsed three times with DI water. In each of the pipette cleaners, we also suspended an electric actuator line (made of Neoprene). In one of the pipette cleaners, the actuator line was covered with a watertight sleeve of LDPE similar to what had been used previously in the field study (Fig. 2-1). The other actuator line was left unshielded to determine if the Neoprene itself leached contaminants. The pipette washers were covered to shield them from light and dust particles, and then left for the 2-week equilibration period.

Figure B-1. Pipette cleaner with Snap Sampler string and shielded actuator line.

After 2 weeks, the samplers were removed from the pipet cleaners, and subsamples were then collected from the Snap Samplers and the DI water in the two pipet washers. The samples were labeled, placed on ice, and immediately shipped to the contract laboratory for analyses. The samples were analyzed for the same suite of analytes as in the field demonstration

B.2.1.2 Equipment Blanks for the RGC Samplers

Two RGC samplers (that had been constructed the previous day) were placed in the sparging tank filled with DI water (Fig. 5-3). They were sparged with nitrogen gas for approximately 24 hours. Fresh DI water was then collected from the water purification

system for analysis, and the sparge tank was emptied, rinsed three times with DI water, and refilled with once more with DI water. The sparge chamber was covered to keep out light, and the samplers were then left to for 2 weeks to determine if any constituents leached from these samplers.

After 2 weeks, the samplers were removed from the sparging tank, and subsamples were then collected from the RGC samplers and the DI water in the sparge tank. The samples were labeled, placed on ice, and immediately shipped to the contract laboratory for analyses. The samples were analyzed for the same suite of analytes as in the field demonstration

B.2.1.3 Equipment Blank Results

The results for the laboratory water used in the equipment-blank study can be found in Table B-1.For the anions and VOCs, concentrations were not above the reporting limit (RL).The same was true for the dissolved metals, except for Cu, and Zn, where concentrations were slightly above the RL. For the total metals, concentrations were below the RL, except for Mn, Na, and Zn, where concentrations were slightly above the RL.

Table B-1. Summary of findings for laboratory water used in the equipment blanks

Analysis	Compound	Concentration µg/L	
		Water Supply	Reporting Limit
VOCs	All	ND	
Total Metals	Manganese	3.5	1
	Sodium	69	50
	Zinc	15	5
	All others	ND	
Anions	Chloride	ND	200
	Sulfate	ND	500
Dissolved Metals	Copper	6.9	1
	Zinc	15	5
	All others	ND	
Field iron (2)	Total Fe(2)	ND	10
	Dissolved Fe(2)	ND	10

Table B-2 gives the results for the Snap Sampler blanks. The first pipet washer contained the electronic actuator cable for the Snap Sampler that was covered with a layer of Polyethylene (PE) (to prevent possible leaching from the Neoprene covering on the cable). This sample did not contain any leached contaminants with the possible exception of dissolved Zn, which was elevated in the pipet washer but not in the Snap Sampler. Dissolved Zn was approximately three times the report limit in the laboratory water samples as well.

Table B-2. Summary of blank snap sampler findings.

	Analytes	Concentration µg/L		
		Pipet Stand	Snap Sampler	Reporting Limit
Pipet Washer no. 1 with poly sleeve				
VOCs	All	ND	ND	0.5
Total Metals	Zinc	5.1	ND	5
	All others	ND	ND	
Anions	Chloride	ND	ND	200
	Sulfate	ND	ND	500
Dissolved Metals	Barium	1.1	ND	1
	Zinc	54	ND	5
	All others	ND	ND	
Pipet Washer no. 2 with no poly sleeve (neoprene exposed)				
VOCs	Acetone	ND	13	10
	All others	ND	ND	
Total Metals	Calcium	51	57	50
	Zinc	8.3	7.5	5
	All others	ND	ND	
Anions	Chloride	ND	ND	200
	Sulfate	ND	ND	500
Dissolved Metals	Copper	1.7	ND	1
	Zinc	11	5.9	5
	All others	ND	ND	

The second pipet washer contained the actuator with no PE sleeve. Again analyte concentrations indicated that there were no substantially elevated concentrations of any of the analytes of interest. Concentrations of Zn were again slightly elevated as they had been in the laboratory water sample.

Trip blank was ND for VOCs.

Table B-3 gives the results for the RGC sampler blank and the purging tank used in that experiment. None of the VOCs were detected, with the exception of carbon disulfide, which was elevated in the sparge tank and the RGC sampler. Concentrations of the total metals in the sparge tank and in the RGC sampler were all at or below the reporting limit. However, concentrations of dissolved Na and Zn were substantially elevated (150 and 210 µg/L, respectively) for the RGC samplers. It is not clear why this would (or could) be the case.

Table B-3. Summary of blank RGC sampler findings.

	Analytes	Concentration µg/L		
		Sparge tank	RGC sampler	Reporting Limit
RGC sampler & sparge tank				
VOCs	Carbon Disulfide	5.8	12	0.5
	All others	ND	ND	
Total Metals	Copper	1.1	---	1
	All others	ND	ND	
Anions	Chloride	ND	ND	200
	Sulfate	ND	ND	500
Dissolved Metals	Barium	ND	2.3	1
	Copper	2.5	ND	1
	Sodium	57	210	50
	Zinc	7.2	150	5
	All others	ND	ND	

B.3 CALIBRATION OF ANALYTICAL EQUIPMENT

B.3.1 Calibration of Field Instruments

The Horiba (MDL W-22XD) probe was checked 1 month prior to going in the field and then was calibrated each morning using the Horiba Autocalibration solution. This solution was used to calibrate the meter for pH, conductivity, turbidity, and DO. (The other purge parameters are calculated based on these measurements.)

The manufacturer's guidelines were used to calibrate the Hach Colorimeter II for field analyses for Iron (2).

B.3.2 Calibration of Laboratory Instruments

To ensure data validity, standard laboratory practices for analyses included the following:

- Standards preparation and analysis.
- Instrument calibration.
- Instrumentation QC.
- Periodic duplicate analyses.

Certified reference samples were used by the contract laboratory to ensure proper calibration and thus accuracy of the analyses. One out of 40 samples was a certified reference sample (i.e., 2.5%). One out of 20 samples was a calibration standard (i.e., 5%). All certified reference samples should be within 20% of the known values.

The analytical laboratory used standard EPA protocols for calibrating the analytical instrumentation, including calibration curves for at least three standards at different concentrations, internal and external standards, and testing blanks. Any issues were to be reported to the PI immediately.

All laboratory data were reviewed for completeness, detection and quantitation limits, QA/QC analyses, and the adequacy of the holding times by the laboratory supervisor and the PI.

Laboratory blanks were prepared by the contract laboratory using analyte-free reagent water. One laboratory blank was performed for every 20 samples (i.e., 5% of the samples).

B.4 DECONTAMINATION PROCEDURES

In the field, equipment was decontaminated by spraying it with a solution of laboratory detergent, brushing if needed, and rinsing it by spraying it with bottled distilled water.

In the laboratory, equipment was decontaminated by washing it a tub containing a solution of a laboratory detergent and hot water, rinsing it with tap water until there was no further sign of bubbles, and then rinsing three times with house deionized water.

APPENDIX C: RESULTS FROM THE VOC ANALYSES.

Table C1. VOC concentrations in samples collected using the three sampling methods.

Analyte	Reporting Limit	Well #	Concentrations (µg/L)		
			Low-flow	RGC sampler	Snap Sampler
1,1-Dichloroethane	0.5	072	2.5	2	2.4
		136	0.6	ND	0.6
1,1-Dichloroethene		072	4.5	2.9	4
		427	0.8	0.7	0.7
1,2-Dichloroethane		072	3.2	2.5	2.9
		427	6.6	6	5.5
Acetone	10	072	ND	13	ND
		173	ND	26	ND
		211	ND	11	ND
		225	ND	30	ND
		427	ND	ND	23
		1065	ND	31	ND
Carbon Disulfide	0.5	072	0.9	3.8	5.1
		173	ND	0.6	ND
		211	ND	1.2	ND
		225	ND	ND	ND
		400	ND	0.7	ND
		427	ND	0.8	ND
		437	ND	ND	0.5
		1065	ND	1.2	ND
Carbon Tetrachloride	0.5	173	0.9	0.9	1.7
		211	0.8	ND	0.7
		225	1.2	1.1	1.3
		333	1.9		1.6
		427	20	12	16
		437	2.6	1.1	0.6
Chloroform	0.5	400	1.5	1.4	1.6
		427	9.9	8.9	7.9
***cis*-1,2-Dichloroethene**	0.5	072	1.8	1.3	1.6
		400	4.6	3.4	4.6
		427	3.3	3	2.8
		437	0.5	ND	ND
		1065	1.2	0.9	1.2
m,p-Xylenes	0.5	072	1.4	ND	0.7
MTBE	0.5	072	1.6	5.6	ND
		136	11	29	18

Analyte	Reporting Limit	Well #	Concentrations (µg/L)		
			Low-flow	RGC sampler	Snap Sampler
		173	ND	10	4.4
		211	3.9	27	7.7
		225	ND	16	ND
		333	2.2		1.5
		400	1	9.8	1.7
		427	ND	6.9	55
		437	ND	10	ND
		1065	3.2	16	2.6
o-Xylene	0.5	072	0.9	ND	ND
Tetrachloroethene	0.5	427	67	35	60
		1065	1.4	0.5	1.4
Toluene	0.5	072	0.5	ND	ND
		211	0.5	1.1	ND
		333	0.5		ND
		427	ND	ND	0.8
Trichloroethene	0.5	072	3.5	2.4	3.3
		136	2.2	1.4	1.7
		173	5.1	5	9.3
		211	6.3	4.8	6.2
		225	2.7	2.8	3.1
		333	1.3		1.4
		400	100	90	110
		427	110	93	93
		437	4.1	1.4	0.9
Trichlorofluoromethane	1	427	2.2	1.9	1.9
Vinyl Chloride	0.5	072	3.4	2.4	3
Toluene	0.5	136	ND	1	0.6

Table C2. Summary of the statistical analyses.

Analyte		Significant Difference?	Test	P	Significant Difference?		
					LF & RGC	RGC & SS	LF & SS
carbon tet*		NS	Friedman	0.124	N/A	N/A	N/A
cDCE*		NS	RM-ANOVA	0.101	N/A	N/A	N/A
MTBE*		Yes	RM-ANOVA on ln	<0.001	Yes	Yes	No
TCE		Yes	Friedman	0.047	Yes	No	No
RM-ANOVA = Repeated Measures Analysis of Variance							
Friedman = Friedman RM-ANOVA on ranks							
* The reporting limit was used for analyte concentrations that were below the detection limit.							

Table C3. Summary of linear-least-fit analyses for the VOC data.

Sampling Comparison	Analyte	R^2	Regression Sig. level	Regression significant?	Slope	Relation of slope to 1.00?	Slope = 1.00?
SS vs. LF	**Carbon Tetrachloride**	0.988	3.70×10^{-5}	Yes	0.79	<	No
	cDCE	0.995	0.000111	Yes	0.95	=	Yes
	MTBE	0.138	0.264	No	1.7	=	Yes
	MTBE - MW 427	0.928	1.96×10^{-5}	Yes	1.5	>	No
	TCE	0.982	1.55×10^{-7}	Yes	0.96	=	Yes
RGC vs. LF	**Carbon Tetrachloride**	0.997	5.22×10^{-5}	Yes	0.60	<	No
	cDCE	0.990	0.000285	Yes	0.79	<	No
	MTBE	0.717	0.00280	Yes	3.4	>	No
	TCE	0.999	4.81×10^{-10}	Yes	0.87	<	No
RGC vs. SS	**Carbon Tetrachloride**	0.996	6.80×10^{-5}	Yes	0.75	<	No
	cDCE	0.972	0.00130	Yes	0.83	=	Yes
	MTBE	0.178	0.229	No	0.36	<	No
	MTBE – MW 427	0.723	0.00563	Yes	2.0	=	Yes
	TCE	0.989	2.39×10^{-7}	Yes	0.89	<	No

APPENDIX D: RESULTS FOR THE DISSOLVED INORGANIC ANALYTES

Table D1. Results from the analyses of the dissolved metals.

Analyte	Reporting Limit (µg/L)	Well no.	Concentration (µg/L)		
			LF	RGC	SS
Aluminum	50	173	ND	60	ND
Antimony	1	136	ND	1	ND
		211	ND	3.1	ND
Arsenic	1	072	3.5	6.1	5.7
		136	1.5	1.5	1
		173	3	3.2	3.1
		211	2.6	2.6	2.1
		225	3	3.2	3.4
		333	3		3
		400	2.4	2.7	2.3
		427	1.6	1.8	1.9
		1065	2.6	3	2.7
Barium	1	072	77	140	120
		136	54	60	56
		173	47	48	47
		211	67	63	64
		225	49	54	48
		333	41		42
		400	90	95	85
		427	170	180	180
		437	45	45	45
		1065	53	54	50
Cadmium	1	400	6.1	1.2	8.4
Calcium	50	072	19000	22000	23000
		136	19000	20000	21000
		173	13000	13000	13000
		211	20000	20000	20000
		225	14000	14000	14000
		333	13000		14000
		400	30000	31000	28000
		427	58000	64000	64000
		437	13000	13000	13000
		1065	19000	19000	18000
Chromium	1	136	3.6	3.4	1.9
		173	13	15	16
		211	75	12	14
		225	15	14	25

Analyte	Reporting Limit (µg/L)	Well no.	Concentration (µg/L)		
			LF	RGC	SS
		333	13		14
		400	8.9	9.8	8.5
		427	7	7.5	7.8
		437	13	13	13
		1065	11	10	11
Cobalt	1	136	6.2	9.2	8.1
		211	2.2	ND	ND
Copper	1	072	ND	8	1.2
		136	15	1.6	2
		211	4.3	4	2.5
		225	ND	ND	1.1
		333	1		2.1
		400	1.6	1.9	1
		427	ND	ND	3
		437	ND	1.6	1.1
		1065	ND	1.2	4.1
Iron	50	072	1400	6000	3600
	100	211	340	ND	ND
Fe (2) Field	10	072	970	3300	
		136	60	ND	ND
		173	ND	10	
		211	ND	ND	ND
		225	ND	ND	ND
		333	ND		
		400	ND		ND
		427	ND		
		437	ND		ND
		1065	ND	ND	ND
Magnesium	50	072	12000	14000	14000
		136	14000	15000	15000
		173	9900	10000	9900
		211	15000	15000	14000
		225	9900	9900	9800
		333	9400		9600
		400	21000	22000	19000
		427	40000	44000	45000
		437	9500	9700	9400
		1065	12000	13000	12000
Manganese	1	072	140	230	240
		136	50	69	63

Analyte	Reporting Limit (µg/L)	Well no.	Concentration (µg/L)		
			LF	RGC	SS
		173	1.1	ND	ND
		211	25	3.4	4.9
		225	ND	ND	ND
		427	1.2	1.2	1.8
		1065	6.8	3.8	3.2
Molybdenum	1	072	1.9	2.1	2.2
		136	1.2	1.5	1.2
Nickel	1	136	880	1100	1100
		173	5.5	7.6	2.3
		211	59	27	52
		225	8.2	9.3	6.9
		333	36		34
		400	1.1	ND	1.4
		427	5.7	4.3	7.3
		1065	87	69	51
Potassium	100	072	1200	1300	1300
	50	136	1600	1700	1700
	100	173	1100	1200	1100
	50	211	1500	1500	1500
	50	225	1200	1900	1200
	50	333	1100		1100
	50	400	1700	1800	1700
	50	427	2100	2700	2300
	50	437	1100	1200	1100
	50	1065	1500	1600	1300
Sodium	60	072	16000	17000	16000
		136	17000	17000	18000
		173	13000	14000	13000
		211	16000	17000	16000
		225	14000	14000	14000
		333	14000		14000
		400	22000	23000	22000
		427	27000	30000	30000
		437	13000	13000	13000
		1065	23000	23000	23000
Vanadium	1	072	5.4	2	1.4
		136	13	12	11
		173	28	30	29
		211	24	22	21
		225	30	30	30
		333	29		30

Analyte	Reporting Limit (µg/L)	Well no.	Concentration (µg/L)		
			LF	RGC	SS
		400	24	26	23
		427	19	20	20
		437	30	30	30
		1065	20	20	20
Zinc	5	136	ND	5.2	ND
		173	ND	5.3	7.3
		211	6.8	11	ND
		225	ND	ND	11
		333			6.5
		400	33	17	50
		427	ND	5.1	5.6
		437	ND	7.3	6.4
		1065	ND	5.9	ND

Table D2. Summary of linear-least-fit analyses for the dissolved metals.

Sampling Comparison	Filtered Analytes	R^2	Regression Sig. level	Regression significant?	Slope	Relation of slope to 1.00?	Slope = 1.00? *
SS vs. LF	As	0.944	7.79×10^{-6}	Yes	1.12	=	Yes
	Ba	0.959	2.71×10^{-6}	Yes	1.12	=	Yes
	Ca	0.995	1.22×10^{-10}	Yes	1.06	>	Yes
	Cr	0.447	0.0385	Yes	0.34	<	Yes
	Cr - outliers	0.994	3.56×10^{-6}	Yes	1.06	=	Yes
	Mg	0.993	4.08×10^{-10}	Yes	1.06	=	Yes
	Ni	0.997	6.52×10^{-9}	Yes	1.24	>	No
	K	0.996	5.54×10^{-11}	Yes	1.02	=	Yes
	Na	0.998	2.91×10^{-12}	Yes	1.03	=	Yes
	V	0.994	2.11×10^{-10}	Yes	0.99	=	Yes
RGC vs. LF	As	0.950	2.55×10^{-5}	Yes	1.23	=	Yes
	Ba	0.959	2.71×10^{-6}	Yes	1.12	=	Yes
	Ca	0.998	6.09×10^{-11}	Yes	1.07	>	No
	Cr	0.468	0.0476	Yes	0.27	<	No
	Cr – outlier	0.992	1.30×10^{-6}	Yes	1.01	=	Yes
	Mg	0.999	2.00×10^{-11}	Yes	1.08	>	No
	Ni	0.997	1.12×10^{-7}	Yes	1.24	>	No
	K	0.982	1.46×10^{-7}	Yes	1.15	>	No
	K - outliers	0.999	3.09×10^{-9}	Yes	1.06	>	No
	Na	0.998	3.99×10^{-11}	Yes	1.05	>	No
	Na - outlier	0.999	1.17×10^{-10}	Yes	1.03	=	Yes
	V	0.995	1.90×10^{-9}	Yes	1.01	=	Yes

Sampling Comparison	Filtered Analytes	R^2	Regression Sig. level	Regression significant?	Slope	Relation of slope to 1.00?	Slope = 1.00? *
RGC vs. SS	As	0.993	8.01×10^{-8}	Yes	1.07	=	Yes
	Ba	0.996	1.06×10^{-9}	Yes	1.06	=	Yes
	Ca	0.998	2.95×10^{-11}	Yes	1.01	=	Yes
	Cr	0.936	5.35×10^{-5}	Yes	0.79	<	No
	Cr - outlier	0.995	2.08×10^{-6}	Yes	0.95	=	Yes
	Mg	0.997	3.70×10^{-10}	Yes	1.01	=	Yes
	Ni	0.999	4.10×10^{-9}	Yes	1.00	=	Yes
	K	0.983	1.25×10^{-7}	Yes	1.12	>	No
	Na	0.999	1.30×10^{-11}	Yes	1.01	=	Yes
	V	0.998	4.39×10^{-11}	Yes	1.03	=	Yes

*Is the slope was significantly different from 1.0?

Table D3. Results from the statistical analyses of the dissolved metal data.

	Comparison of three sampling methods			Results from multiple comparison tests				
Analyte	Significant difference? Yes, No	Test	*P*=	Significant difference between two methods?				
				LF & RGC		RGC & Snap		LF & Snap
As	No	Freidman RM ranks	0.079					
Ba	**Yes**	RM ANOVA	0.018	**Yes**	RGC > LF	No		No
Ca	No	Freidman RM ranks	0.569					
Cr	No	Freidman RM ranks	0.654					
Mg	**Yes**	RM ANOVA	<0.001	**Yes**	RGC > LF	**Yes/No***	RGC > SS	No
Ni	No	RM ANOVA	0.212					
K	**Yes**	RM ANOVA	<0.001	**Yes**	RGC > LF	**Yes**	RGC > SS	No
Na	**Yes**	Yes, RM ANOVA on ln	0.032	**Yes/No***	RGC > LF	No		No
V	No	RM ANOVA	0.325					

*According to the Holm-Sidak Multiple Comparison test there is a significant difference. However, according to a paired-*t* test there is no significant difference.

APPENDIX E: RESULTS FROM THE ANALYSES OF TOTAL INORGANIC ANALYTES

Table E1. Total anion concentrations in the wells.

Well #	Chloride Conc. (mg/L)			Sulfate Conc. (mg/L)		
	Reporting limit	Low-flow	Snap Sampler	Reporting limit	Low-flow	Snap Samper
072	0.20		17	0.50		1.1
136	0.40	25	25	0.50	13	13
173	0.20	11	11	0.50	1.1	1.2
211	0.40	22	22	0.50	3.8	3.9
225	0.20	13	14	0.50	1.5	1.6
333	0.20	11	11	0.50	1.2	1.2
400	0.40	23	24	0.50	3.9	3.1
427	1.0	89	92	0.50	15	14
437	0.20	11	11	0.50	1.2	1.2
1065	0.40	19	19	0.50	2.4	2.5

Table E2. Results of the statistical analyses for the chloride and sulfate data.

Analyte	Significant difference? Yes, No	Preferred Test	P=
Chloride	No	Wilcoxon	0.250
Sulfate	No	Wilcoxon	1.00

Table E3. Summary of linear-least-fit analyses for total inorganics (for low-flow sampling vs. the Snap Sampler).

Analyte Type: SS vs. LF						
Analyte	R^2	Regression Sig. level	Regression significant?	Slope	Relation of slope to 1.00?	Slope =1.00?
Chloride	1.000	2.07×10^{-14}	Yes	1.03	>	No
Sulfate	0.998	1.38×10^{-10}	Yes	0.96	=	Yes
Total Analytes	R^2	Regression Sig. level	Regression significant?	Slope	Relation of slope to 1.00?	Slope = 1.00?
As	0.994	2.59×10^{-10}	Yes	1.07	=	Yes
Ba	0.979	3.56×10^{-8}	Yes	1.06	=	Yes
Ca	0.996	5.29×10^{-11}	Yes	1.02	=	Yes
Cr	0.516	0.0147	Yes	1.93	=	Yes
Co	0.850	0.00210	Yes	1.41	=	Yes
Cu	0.739	0.000997	Yes	1.46	=	Yes
Fe (lab)	0.858	0.000633	Yes	1.39	=	Yes
Mg	0.999	7.73×10^{-13}	Yes	1.03	=	Yes
Mn	0.916	9.29×10^{-6}	Yes	1.51	>	No
Ni	0.991	1.32×10^{-8}	Yes	1.27	>	No
K	0.996	5.51×10^{-11}	Yes	0.99	=	Yes
Na	0.999	3.31×10^{-13}	Yes	1.00	=	Yes
V	0.993	3.18×10^{-10}	Yes	1.06	=	Yes
Zn	0.350	0.100	No	0.35	<	No

Table E4. Comparison of total metal concentration in the Snap Sampler and low-flow sampling.

Analyte	DL	Well #	Concentration (µg/L) unless marked with an *		Analyte	DL	Well #	Concentration (µg/L) unless marked with an *	
			Low-flow	Snap Sampler				Low-flow	Snap Sampler
As	1	072	5.7	6.6	Co	1	072	—	—
		136	1.6	1.6			136	6.7	8.6
		173	3.4	3.4			173	1.6	1.9
		211	2.4	2.8			211	1.9	4.3
		225	3.3	3.6			225	1.9	5.4
		333	3.9	3.7			333	BDL	3.8
		400	2.3	2.3			400	—	—
		427	1.9	1.8			427	BDL	BDL
		437	3.3	3.3			437	1.4	BDL
		1065	2.6	2.9			1065	1.7	BDL
Ba	1	072	89	130	Cu	1	072	1.7	BDL
		136	58	59			136	2.9	2.9
		173	50	52			173	2.9	8.9
		211	63	66			211	3.6	6.8
		225	53	53			225	3.9	6.3
		333	44	51			333	2.6	8.1
		400	91	84			400	1.6	2.1
		427	170	170			427	4.5	2.6
		437	45	46			437	2.1	BDL
		1065	55	56			1065	3.5	4.7
Ca*	0.05*	072	20	24	Fe*	0.05*	072	4.2	5.6
		136	20	21			136	1.8	2.6
		173	13	14			173	0.32	0.46
		211	19	20			211	0.28	0.85

Analyte	DL	Well #	Concentration (µg/L) unless marked with an *		Analyte	DL	Well #	Concentration (µg/L) unless marked with an *	
			Low-flow	Snap Sampler				Low-flow	Snap Sampler
		225	15	13			225	0.32	1.5
		333	14	13			333	0.14	2.5
		400	30	28			400	—	—
		427	58	60			427	0.49	1.1
		437	13	13			437	—	—
		1065	19	20			1065	0.41	0.31
Cr	1	072	5.3	3.4	Fe (2) †	10	072	1300	—
		136	140	130			136	BDL	160
		173	81	130			173	BDL	200
		211	59	220			211	BDL	40
		225	76	370			225	10	BDL
		333	28	330			333	BDL	50
		400	9.7	11			400	BDL	BDL
		427	73	91			427	BDL	60
		437	14	16			437	20	10
		1065	76	74			1065	BDL	100
Mg*	0.05	072	13.0	15.0	K*	0.05*	072	1.2	1.3
		136	14.0	15.0			136	1.6	1.7
		173	10.0	10.0			173	1.1	1.2
		211	14.0	14.0			211	1.4	1.4
		225	10.0	9.6			225	1.3	1.3
		333	9.8	9.5			333	1.2	1.1
		400	21.0	21.0			400	1.7	1.5
		427	41.0	42.0			427	2.1	2.1
		437	9.3	9.3			437	1.1	1.1

Analyte	DL	Well #	Concentration (µg/L) unless marked with an *		Analyte	DL	Well #	Concentration (µg/L) unless marked with an *	
			Low-flow	Snap Sampler				Low-flow	Snap Sampler
		1065	12.0	13.0			1065	1.5	1.4
Mn	1	072	150	230	Na*	0.06*	072	17.0	17.0
		136	60	67			136	17.0	17.0
		173	20	23			173	14.0	14.0
		211	23	49			211	15.0	15.0
		225	29	79			225	15.0	14.0
		333	3.4	64			333	14.0	14.0
		400	BDL	3			400	22.0	21.0
		427	4	4.8			427	27.0	28.0
		437	BDL	1.8			437	13.0	14.0
		1065	20	9.2			1065	24.0	24.0
Mo	1	072	1.9	2.2	V	1	072	8.7	4.1
		136	1.6	1.7			136	15	14
		173	BDL	1.2			173	29	33
		211	BDL	2.5			211	22	24
		225	1.2	5.4			225	33	36
		333	1.4	4.1			333	32	36
		400	—	—			400	24	24
		427	BDL	BDL			427	19	20
		437	—	—			437	30	31
		1065	1.2	1			1065	22	22
Ni	1	072	860	1100	Zn	5	072	5.6	5
		136	10	7.7			136	7.6	6.2
		173	51	61			173	6	BDL
		211	34	62			211	5.5	5.4

Analyte	DL	Well #	Concentration (µg/L) unless marked with an *		Analyte	DL	Well #	Concentration (µg/L) unless marked with an *	
			Low-flow	Snap Sampler				Low-flow	Snap Sampler
		225	44	62			225	6	BDL
		333	42	120			333	BDL	14
		400	1.4	BDL			400	31	BDL
		427	8.9	9.5			427	—	—
		437	BDL	1.1			437	—	—
		1065	110	60			1065	BDL	8

DL= Detection limit

BDL= Below the detection limit

* Concentrations are in mg/L

† Field measurement

Table E5. Results of the statistical analyses for analytes with acceptable variability between field duplicates.

Analyte	Significant difference? Yes, No	Preferred Test	*P*=
As	No	Wilcoxon	0.156
Ba	No	Wilcoxon	0.109
Ca	No	Paired *t*	0.413
Mg	No	Wilcoxon	0.156
K	No	Paired *t*	0.758
Na	No	Wilcoxon	1.0
Zn	No	Paired *t* ln	0.655

Statistical tests included the following: Wilcoxon Signed Rank test, paired-*t* test on raw data, and paired-*t* test on ln values.

P value is the probability of being wrong in concluding that there is a true difference between the two sampling methods. The smaller the *P* value, the more likely the two methods are different. Typically, there is a significant difference when $P < 0.05$.

Table E6. Results of the statistical analyses for analytes with unacceptable variability between field duplicates.

Analyte	Significant difference? Yes, No	Preferred Test	*P*=
Cr	No	Paired *t* ln	0.077
Co	No	Paired *t*	0.06
Cu	No	Paired *t*	0.149
Fe	Yes	Paired *t*	0.016
Mn	Yes	Paired *t* ln	0.038
Mo	No	Paired *t*	0.065
Ni	No	Paired *t* ln	0.509
V	No	Paired *t*	0.281

Statistical tests included the following: Wilcoxon Signed Rank test, paired-*t*-test on raw data, and paired-*t*-test on ln values.

P value is the probability of being wrong in concluding that there is a true difference between the two sampling methods. The smaller the *P* value, the more likely the two methods are different. Typically, there is a significant difference when $P < 0.05$.

Table E7. Field notes: visual inspection of samples.

Well #	Comments
72	Crap on top of sampler, picture of sample in beaker
173	Bottom RGC sampler “crudded” up
333	Particulates in bottom snap
1065	Some particles in samples
225	Huge chunk of rusted metal
136	Orange sediment bottom snap, debris on bottom RGC sampler
427	A lot of iron precipitate in the bottom of the Snap VOA vial

Table E8. Construction information on wells.

Well #	Depth to water (ft btoc)	Top of screen (ft bgs)	Screen length (ft)	Sampling depth (ft bgs)	Depth below watertable (ft)	Year of Construction	Casing Material	Screen Material	Screen type	Screened Interval	Well #
72	103	121	10	126	23	1985	low carbon steel	low carbon steel	Slotted		MW-72
136	102	230	15	237.5	135.5	??	PVC	Stainless	Slotted	coarse sand	MW-136
173	115	156	10	161	46	1989	PVC	Stainless	Slotted	silty sand	MW-173
211	109	151	10	156	47	1990	PVC	Stainless	Slotted	sand	MW-211
225	114	157.6	10	162.6	48.6	1990	PVC	Stainless	Slotted	3 layers: silty sand, sand, & silty sand	MW-225
333	112	160	10	165	53	??	??	??	??	2 layers: sand & sandy clay	MW-333
400	105	111	10	116	11	1997	PVC	Stainless	Slotted	silt & sand layers	MW-400
427	108	114	10	119	11	1998	PVC	Stainless	Slotted	all silt	MW-427
437	110	160	10	165	55	1998	PVC	Stainless	Slotted	coarse sand	MW-437
1065	112	121	10	126	14	1990	PVC	Stainless	Slotted	3 layers: sand, sandy silt, & silty sand	MW-1065

Table E9. Purge parameter readings at the beginning and end of low-flow sampling. Wells ranked from shallowest to deepest wells.

Well #	Initial DO mg/L	Final DO mg/L	Initial ORP mV	Final ORP mV	Initial pH	Final pH	Initial turbidity NTU	Final turbidity NTU	Purge time (hr:min)	Comments
MW-400	7.59	7.5	249	220	6.71	6.96	6.8	50.3	1	Values kept climbing
MW-427	5.63	5.39	197	179	6.43	6.57	95.2	34.2	1:06	
MW-1065	5.7	5.48	190	57	6.19	6.8	27.5	12.2	1:12	
MW-72*	2.67*	1.26*	–177*	–173*	6.88	7.07	34	32.5	0:43	
MW-211	6.27	5.91			6.32	6.65	20.3	13.3	0:34	
MW-173	6.44	5.22	196	179	6.42	6.76	98.6	136	0:47	Values kept climbing
MW-225	5.57	5.17	197	195	6.51	6.85	7.4	5.3	1:12	
MW-333	5.17	4.94	175	189	6.58	7.02	9.4	5.3	0:40	
MW-437	5.78	5.37	251	233	6.25	6.69	1.3	2.3	1:00	
MW-136*	1.77*	1.38*	21	–25*	6.57	6.96	105	39.8	2:16	

* Anoxic well

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14. ABSTRACT

Objectives of this demonstration/validation project were to determine whether the Snap Sampler passive ground water sampling device can provide: 1) technically defensible analytical data for the wide spectrum of analytes that are of concern to the Department of Defense and 2) substantial cost savings over currently used ground water sampling methods. This particular demonstration was conducted at the former McClellan Air Force Base in Sacramento, CA. Ten wells were sampled using the Snap Sampler, low-flow purging and sampling, and the dialysis (or regenerated cellulose) membrane passive sampler. Analytes included dissolved and total inorganics (including non-metal anions, metalloids, and metals), and four Volatile Organic Compounds (VOCs) (including three chlorinated solvents and methyl tert-butyl ether [MTBE]). Analyte concentrations in samples collected with the two passive sampling methods were compared with concentrations found in samples collected using low-flow sampling. Cost analyses were also conducted to compare the cost of conducting quarterly sampling on a similar site with 50 wells using the three sampling methods.

15. SUBJECT TERMS
Dialysis membrane sampler
Equilibrated-grab sampler
Low-flow sampling
Passive groundwater sampling
Regenerated cellulose sampler
Snap Sampler

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